A CONCURRENT ENGINEERING FRAMEWORK FOR APPAREL MANUFACTURE

by

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(ABSTRACT)

The purpose of the present study was to develop a concurrent engineering (CE) apparel framework. Sequential manufacturing is the traditional production method for apparel manufacture. Sequential design and product development impact manufacturing more than any other process because design decisions can have costly production implications. To improve this process, other industries have implemented CE. CE is the concurrent design of products and their related manufacture and support processes. Reported CE benefits are time, cost, and quality improvements. A review of CE literature showed no application of CE for apparel manufacture.

The present study was an interpretational qualitative case study of apparel manufacturers with two phases: Phase One was a descriptive documentation mapping the *as is* environment. Phase Two was the development of a *to be* environment that integrated apparel design with product development. The apparel manufacturer sample was located in U.S. representing multiple merchandise classifications. Sample size for Phase One was 72 subjects and 36 subjects for Phase Two. A triangulated data collection method combined interviewing, reading company documents, observing, and giving questionnaires to focus groups.

Phase One results and discussion narrative are 101 $IDEF_0$ analytic graphic diagrams and identification of process performance weaknesses for the *as is* environment. $IDEF_0$

diagrams include: create apparel line, develop colors and prints, implement fabric and special operations, set production specifications, and produce samples. Findings documented the *as is* environment as a sequential process with rework cycles occurring in all functional areas. The *as is* environment had time-to-market delays, excess cost, and decreased process quality.

Phase Two results and discussion for the *to be* environment was the development of a CE apparel framework. The findings are illustrated in 80 $IDEF_0$ diagrams with reorganization of apparel activities, inclusion of multi-disciplinary design teams, and use of enabling technology. The *to be* environment findings show apparel activities did not remain sequential. Apparel activity movement supports the CE design maturity curve concept in which apparel design decisions moved later, and manufacturing and costing decisions are made earlier. An apparel associate focus group indicated that the *to be* environment could improve moderately for time-to-market, excess cost, and process quality.

DEDICATION

I am dedicating my dissertation to my wonderful parents,

All my life my parents have supported, encouraged, and helped me pursue my highest dreams to become the person that I am today. Without my parents this dissertation would never have been possible. I admire my parents, and I would be honored to share the title of Doctor of Philosophy with them.

I would like to give special recognition to my grandparents.

strongly encouraged learning and believed in education. I often have felt

presence, with their thoughts of, "We know you can make it." I believe in fate, and my interest in improving the apparel industry must have come from

In the 1920s, worked as a sewing operator in a Canadian glove factory. She left the glove factory, and moved to California with the comment, "I'll never do that again!" description of her job revealed that little has changed in apparel manufacture in 70 years. My recommendations for a new apparel design process are for you, Grandma!

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I would like to gratefully acknowledge the United States Department of Energy. The extensive data collection and type of qualitative research study would not have been possible without the United States Department of Energy's Integrated Manufacturing Predoctoral Fellowship.

As a Ph.D. student and researcher, I sincerely appreciate all of the time and effort put forth by the following individuals and organizations. To do so, I would like to quote one of the apparel associates, in the present research study, for a most appropriate thought, "I tell my folks all the time, there's no big me and little you. We are all here at the same level, whether you are the door person or whether you are the manager, it takes all of that to get the job done."

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CHAPTER I. INTRODUCTION

Statement of the Problem

One of America's largest employers of manufacturing workers is under siege from foreign competition (Commission Working Group on the Textile Industry, 1989). Critical for the U.S. economy, 1994 Fiber/Textile/Apparel (FTA) complex shipments were valued at 111 billion dollars. Apparel production in 1994, valued at 36.5 billion dollars, indicates that apparel is a significant portion of the FTA complex (Standard & Poor's, 1996). In 1992 the FTA complex accounted for 9.4% of U.S. manufacturing employment (U.S. Department of Labor, Bureau of Labor Statistics, 1994c). In 1990, the FTA complex was larger than the automobile, steel, and chemical refining manufacturing industries combined (Moncarz, 1992). Yet, some authorities have questioned whether the U.S. is able to successfully manufacture its own clothing. From 1973 through 1996, U.S. apparel manufacturing employment has decreased from a high of 1.4 million to 846,000 (News Notes, 1996; Standard & Poor's, 1996). In 1995, the U.S. apparel manufacturing sector experienced a 10% drop in domestic employment with the loss of 90,000 apparel manufacturing positions to foreign countries (Keenan, 1996). Typical apparel manufacturer after-tax profits range from 1% to 2% which is lower than most general manufacturing sectors (Standard & Poor's, 1996).

U.S. manufacturing companies are under tremendous pressure to attain a competitive advantage (Porter, 1985). The changing rules of global competition have required change for many companies (Hammer, 1996; Labich, 1994) including the apparel business (Black, 1994). U.S. manufacturers face many challenges that include (a) inconsistent market growth and inconsistent consumer demand, (b) changeable competition, (c) pressure to produce the highest quality product for the lowest cost, and (d) demand for customer responsiveness (Carver & Bloom, 1991; Hammer & Champy,

1993; Committee on Analysis, 1991; Wheelwright & Clark, 1992). Fashion retailers note that changing consumer lifestyles create more demands on retailers and apparel manufacturers (Hostetter, 1996). For survival, apparel companies need to have strong relationships with retail customers to meet consumers' changing needs (Standard and Poor's, 1996). The apparel industry faces unique challenges when manufacturing its product, including (a) the type of raw material used, (b) the limitations of large production runs, (c) the limitations of automated equipment, (d) short product life cycles, (e) variable product life cycles, (f) the high seasonality of product lines, (g) co-location, and (h) dependence on fashion acceptance (Dickerson, 1991; Jernigan & Easterling, 1990).

The American Apparel Manufacturers Association (AAMA) (1994) noted that apparel manufacturers' conventional cost measurement weakens competitiveness. Some company costs are identified; however, up to 75% of a company's total costs are hidden. To increase bottom line profits, companies need to address hidden costs. An organization's hidden costs include expenses of operations, training, product maintenance, distribution, inventory, equipment support, supply support, and product disposal (Blanchard, Verma & Peterson, 1995; Blanchard & Fabrycky, 1990).

Not considered innovative, the apparel industry has been slow to embrace new technologies. The Commission Working Group on the Textile Industry (1989) stated the primary reason for lack of apparel industry change has been the predominance of small firms with limited financial resources. Moncarz (1992) noted the FTA industrial decline is due to (a) weak communication between the fiber, textile, and apparel sectors making up the FTA complex, (b) inadequate funding for design research and development, and (c) an inability to deliver what consumers want.

Change is necessary for textile and apparel industries' survival (Berkstresser & Buchanan, 1986). Domestic garment producers with *business as usual* attitudes have not

survived (American Apparel Manufacturers Association [AAMA], 1984). The adoption of new changes in business practices and advanced technologies has impacted the labor and manufacturing practices in the apparel industry (U.S. Department of Labor Bureau of Labor Statistics, 1994a). Some apparel manufacturers have adopted established philosophies such as Total Quality Management (TQM), Just-in-Time (JIT) manufacturing (Knapton, 1990), or reengineering business process improvements (Hammer, 1996). Some technological alternatives have been tried by the U.S. apparel industry to increase productivity and performance. Some alternatives include automation, partnerships, inventory management, Quick Response, and mass customization (Kincade & Cassill, 1993). If implemented properly, the alternatives are successful for apparel production improvements; however, even with the adoption of numerous apparel technologies, many U.S. consumers are still not satisfied with the apparel products marketed (Brown, 1996). The uniqueness of apparel manufacturing does not allow straight transferability of some advanced engineering practices. Standard and Poor's (1996) and the U.S. Department of Labor (1994a) predict that the apparel industry will remain less automated than other U.S. manufacturing industries due to the primary use of the sewing machine, an equipment item that has remained the same for 100 years. To be more competitive, the apparel industry needs to develop paradigms that integrate past knowledge with present technologies (Black, 1994; Willett & Willett, 1992).

Background of the Problem

The apparel industry uses a sequential manufacturing process in which designing, prototyping, producing, distributing, and selling are separate sequential functions (Amacher, Rogers, Vaughn, Rippy, Hunter, Elliott, & Bailey, 1991; Willett & Willett, 1991). As in other sequential manufacturing processes, the design process is isolated. A step in the sequence does not begin until completion of the previous step. Decisions made by apparel associates during designing and manufacturing remain separate, and

communication is limited between these two areas (Willett & Gorin, 1991). A feedback loop exists only between design and early prototype development functions (e.g., patternmaking). In sequential manufacturing, decisions made by designers during the conceptual design stage often have costly effects on later processes and require product redesign or return of the product to previous stages for corrections (Menon, 1992b). Product design often is an extensive procedure that influences manufacturing efficiency. The design approach of *design it now and fix it later* is costly for companies (Blanchard et al., 1995). For product success, designers need to be informed, balanced, involved with others, and be apprised of manufacturing problems (Whitney, 1988).

To evaluate how certain processes (e.g., design) influence an organization, a researcher is required to study an organization's current mode of operation (Pawar & Driva, 1996). An organization's current mode of operation is referred to as the *as is* environment (Concurrent Engineering Research Center [CERC], 1992). Malhotra and Jayaraman's (1990) study, "Design and Development of an Architecture for Computer-Integrated Manufacturing in the Apparel Industry", mapped the *as is* apparel manufacturer environment. The result of the study was a CIM framework for apparel product manufacture. Malhotra and Jayaraman's (1990) study showed the appropriateness of $IDEF_0$ diagramming use for mapping an apparel manufacturing process to identify improvements.

Design is predicted as the next frontier where companies can attain a competitive advantage. Kurt Salmon Associates reported that the design process is the least efficient within the apparel product life cycle and needs further research (qtd. in Moncarz, 1992, p. 7). With the immense choices available to consumers, price and quality of products are often comparable; therefore, product design is the single element that differentiates one product from another (Blaich & Blaich, 1993). Decreased design development time and

increased sensitivity to consumer needs are imperative for companies; otherwise, products are obsolete before or soon after they reach the market (Carter & Stilwell-Baker, 1992; Nilsson, 1992).

Importance of Studying Design Management

Since the design process creates change (Blaich & Blaich, 1993), decisions made during the design stage are important to product raw material selection, manufacture, cost, market, and disposal. During design, the majority of product cost and quality decisions take place before the product is released to manufacturing (Carver & Bloom, 1991). Design and product development impact manufacturing more than any other singular process (Wheelwright & Clark, 1992). The design process accounts for only 5% of the product cost; however, it indirectly controls 75%-80% of the total product cost (Carver & Bloom, 1991; Whitney, 1988). Improving the design process can improve labor-intensive activities in apparel manufacture (Moncarz, 1992).

To achieve a competitive advantage, companies must learn how to manage design and how to integrate design with other industrial activities (Blaich & Blaich, 1993). Managing design is not new; however, developing methods to integrate design into strategic and operational activities is new. Often, design activities have not been considered as important as finance, market, manufacture, and distribution activities. Product designers have limited influence on a company strategic planning and often are involved only after important decisions have been made. Product design decisions placed near the end of the development process reduce designers potential to make significant contributions to corporate goals and objectives (Blaich & Blaich, 1993).

Product Design and Corporate Strategy

Blaich and Blaich's (1993) product design and corporate strategy conceptual framework promotes the importance of design management as a formal activity. The goal

of design management is for a company to integrate design activities with strategic and operational activities, coordinate design resources, and communicate design relevance. The product design and corporate strategy framework has four primary emphases: (a) design contribution to strategic goals, (b) management of design resources, (c) management of the design process, and (d) cultivation of an information and idea network.

Design Contribution to Strategic Goals

Blaich and Blaich (1993) stated that the designer is core to a design management program. Design needs to be a visible, structured program in which the designer acts as a connector with all product creation activities. A design management program needs to include a written design policy and must be part of a company's strategic management.

Design management consensus can be difficult, because designing, marketing, and manufacturing personnel often have conflicting viewpoints (Blaich & Blaich, 1993). Designers generally are concerned with aesthetics, marketing individuals are concerned with selling the product, and manufacturing personnel are concerned with cost-efficient production (Whitney, 1988). Achieving consensus is important for a successful design management program (Blaich & Blaich, 1993).

Design policy. A design policy is a written statement that describes how a company creates, promotes, and supports designed products. A design policy articulates a corporation's identity. Corporate identity is judged by outsiders through a company's policy on design communication (e.g., advertisement), product design (e.g., product quality), and environmental design (e.g., interior work environment) (Blaich & Blaich, 1993).

Sustaining financial support is needed for a successful formal design program. A design policy is effective when endorsed by top management and when money is invested in long term design goals. Design policy failure can lead to an industrial weakness in

creating innovative products. One primary cause of U.S. industrial design weakness is due to insufficient investment in design research and development (Blaich & Blaich, 1993; Porter, 1990a). A lack of design support is often attributed to company executives who use old technology, and cut long term research and development projects (Labich, 1994). The Commission Working Group on the Textile Industry (1989) indicated that research by U.S. apparel manufacturers is extremely weak. U.S. manufacturers were identified as lacking confidence in the ability to compete with products designed in Japan and other Southeast Asian countries. In 1990, U.S. companies spent an average of 0.5% to 1.5% on design research and development. During the same year, Japanese companies spent an average of 4.0%-6.0% on design research and development (Blaich & Blaich, 1993).

Structured design management. Blaich and Blaich (1993) recommended that design be a part of a strategic management plan. The goals of a successful design management program are exemplified when design is (a) planned, (b) integrated into the corporate organization and structured as a formal policy, (c) considered equal during trade-off analyses, (d) considered a formal program, (e) recognized within the corporate structure, (f) important for strategic planning, (g) important to the technical development, production, and marketing processes, (h) viewed as a major contributor to a company strategic values, and (i) followed through in the design-to-market process. A company's structured design management program includes design goals, customer satisfaction, need identification, lifestyle research, and design objectives.

Corporate design goals must be communicated and well managed. Structured design management infers that the design team is proactive rather than reactive. The design team must continually develop new design ideas rather than limit product design to what a company has historically made and sold (Blaich & Blaich, 1993).

A structured design management program is important for companies with short-life products, especially the high-tech, fashion, and entertainment industries. These companies are extremely vulnerable when they fail to detect and shift with customer needs (Labich, 1994). Customer satisfaction goals are met by careful target market definition, consumer need identification, and an analysis of why key customers no longer want certain products (Blaich & Blaich, 1993; Labich, 1994).

The best marketing approach accurately identifies consumer needs. Determining how well a product will sell requires successful marketers to examine underlying consumer behaviors (i.e., beyond what is stated) in order to stimulate a new want (Lorenz, 1986). To pinpoint desired consumer product characteristics, companies need to be user responsive, and make product trade-off decisions based on consumer expectations (Jones, 1973). Companies also need to meet consumer demands for product safety, environmental concerns, product uniqueness, and product ease of use (Blaich & Blaich, 1993). Marketing-oriented apparel companies are design-conscientious, react quickly to the market place, and manufacture high value-added products (Berkstresser & Buchanan, 1986).

Lifestyle research is an in-depth study of consumer needs and wants, called soft values. Lifestyle research differs from traditional market research by using a variety of methods to focus on consumer's sophistication and diverse interests. Target market needs are analyzed by specific demographic and socioeconomic characteristics, buying behavior, organizational memberships, and attitudes. Some lifestyle research results in designing separate products for narrow market segments and in establishing antenna shops (Blaich & Blaich, 1993; Swenson, 1990). Design-satisfying objectives require that a product meets a customer's need, is the price and value the customer is willing to pay, is the best, and most profitable design (Leech, 1972). The key design-satisfying objectives are to (a) adapt technologies to suit functionality, (b) determine whether a

product will sell, (c) respond to user needs and wants, and (d) create aesthetically pleasing products.

Management of Design Resources

Efficient design resource management is an integral part of a successful design program. The goal of managing design resources is to produce a skillfully created product with efficient use of resources. Design resource management encompasses three distinct areas: (a) human resource management, (b) corporate identity management, and (c) capital and financial resource management (Blaich & Blaich, 1993).

Human resource design management is described as recruiting and managing a design staff that best carries out company strategic design goals (Blaich & Blaich, 1993). "Designers are very important to a company as they often make million dollar decisions without ever knowing it" (qtd. in Hyeon, Parsaei, & Sullivan 1993, p. 1). Human resource design management requires structured programs that renew design skills and provide access to design tools and information. Design programs are needed to train designers to satisfy customers, evaluate a design's purpose, evaluate economic implications, and create products for an intended design environment. Designers are sometimes criticized for designing the wrong design solution in terms of time, money, or chance. This situation can frustrate some designers as they expect to be judged on ingenious designs rather than commercially workable designs (Leech, 1972). Programs that renew design skills require (a) continuing education, (b) new tools and techniques, (c) a wide variety of reference literature, (d) research relevant to industry practice, and (e) internal and external partnership communication (Committee on Engineering Design Theory and Methodology, Manufacturing Studies Board, 1991).

Design research information needs to be accessible to employees in an organization. Design libraries are effective for accessing design research information. Successful product designs require design teams to have extensive knowledge of

technical specifications, product design, the manufacturing process, the design process, and a recollection of previous projects. This information includes product use, sell-through, competitor product comparison, compatibility with the company's current product range, and ease of use (Blaich & Blaich, 1993).

Blaich and Blaich (1993) describe corporate identity management as the integration of product design with a company corporate identity. Corporate identity management emphasizes combining product design with communication support services (e.g., advertising, public relations promotions, exhibitions). For effective design management, a company must create a unified corporate identity, ensure that the design process adheres to corporate identity, and ensure that the company communicates corporate identity in its products.

A company needs to provide the capital and financial resources necessary for a design program. To create excellent products faster, company executives need to invest in capital resources such as advanced design tools and advanced design techniques (Blaich & Blaich, 1993). Some advanced design tools that make design information more accessible are computer knowledge-based expert systems, computer networks, and CAD systems (Committee on Engineering, 1991). Financial resource management is proper development and management of design operating budgets. Part of financial resource management is making sure the design team meets time targets and does not go over budget (Blaich & Blaich, 1993).

Management of the Design Process

Effective design process management encompasses strategic design importance, design integration, corporate design programs, and design staffing determination. Strategic design importance communicates a company design commitment throughout an organization. Having strategic design importance means that a company has an overall design direction, consistent design quality, and a structured design program. Design

integration, accomplished through the use of cross functional teams, promotes the early and continuous involvement of design from market research through market launch. Design staff determination is influenced by corporate direction and goals. Managers need to determine whether a design team should be in-house, located at production centers, or if there should be design consultants working as independent contractors (Blaich & Blaich, 1993).

Cultivation of an Information and Idea Network

Design thrives on ideas. Design ideas require continual cultivation through a wide variety of information and the establishment of an idea network. To create a successfully designed product, the designer needs a diversity of perspectives. Design ideas often are generated by personal communication with product designers, design critics, design theorists, and design educators. Companies must support and provide resources so that diverse information sources are available to designers (Blaich & Blaich, 1993).

Importance of Studying Concurrent Engineering

Moncarz (1992) claims that apparel design impacts manufacture, product cost, and product quality more than any other singular process within apparel manufacture. Integrating the design process with product development, including decisions on a product's life cycle, is an important improvement step for apparel manufacturers. Concurrent engineering (CE) is recognized as an important strategy for improving the design process (Moncarz, 1992). According to the Institute for Defense Analysis,

> Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life

> cycle from conception through disposal, including quality, cost, schedule, and user requirements (Winner, Pennell, Bertrand, Slusarczuk, & Marko, 1988, p. 11).

The premise of CE is to develop a high-quality, low-cost product that meets or exceeds consumer needs. CE goals are to (a) consider how the product is used, made, maintained, and disposed of early in the design process, (b) compress product development time, (c) reduce development and production cost, and (d) meet or surpass customer needs and expectations (Carver & Bloom, 1991; Menon, 1992a).

Companies with successful CE implementation use multi-functional teams to significantly reduce design and product development time (Rosenblatt & Watson, 1991; Janson & Lundborg, 1992; Perry, 1990). By looking ahead to the product manufacture during the design stage, a design team uses the CE approach to anticipate and avoid potential manufacturing, quality, and cost conflicts. Companies have benefited with CE implementation by designing products right the first time, limiting the number of unnecessary delays, shortening time-to-market, and developing product specifications with low production costs and high product quality (Carver & Bloom, 1991; Shina, 1991).

Although CE is not in current use by the apparel industry, its use in other industries has been tremendously successful. By having simultaneous design and production considerations, CE implementation lowers costs, reduces time-to-market, meets consumer needs (Rosenblatt & Watson, 1991; Syan, 1994), and abbreviates product development time (Shina, 1991). Apparel manufacturers need the improvements shown by CE implementation to realize greater success in the marketplace (Moncarz, 1992).

Study Justification to Create an Apparel Concurrent Engineering Framework

CE improves sequential manufacturing processes by integrating design and product development. The CE approach was used as the framework to improve the apparel design and product development process. A review of literature indicates CE has been implemented for durable goods products (e.g., military transportation), electronic systems (e.g., circuit boards), and consumer goods (e.g., computers). The uniqueness of apparel manufacture does not allow for strict lateral transferability of CE generic models because it has not been tested on apparel products. Apparel manufacturers in the 1990s face multiple design process challenges: a time-consuming apparel design process, fashion trends having less consumer buying impact, and increased consumer buying of mark-down clothing (Hostetter, 1996; Standard & Poor's, 1996). CE has been shown to reduce time-to-market, reduce total costs, enhance communication for product design, and design products that meet consumer needs (Mills, Beckert, Kempfer, & Chalsma, 1992). An additional benefit of CE is a possible low financial investment, making CE plausible for firms with limited financial resources (Wheeler, 1991). The challenges of apparel industry manufacturing, combined with the benefits of a CE approach, create a need for the development of an CE apparel framework.

The Research Objectives

The purpose of this research was to develop a CE framework for apparel manufacture. The CE approach was the conceptual foundation for integrating apparel design with product development. The research project had two phases. Phase One objectives were to (a) map the functional activities and (b) reveal the inefficiencies (e.g., process delays) of the current design and product development processes (e.g., *as is* environment). Specifically identified were inefficient activities that generated rework or process delays, or increased costs. Phase Two objectives were to (a) create a CE framework for apparel manufacture (e.g., *to be* environment) and (b) evaluate how CE

potentially improves design and product development process inefficiencies discovered during Phase One.

Delimitations

The research limitations were (a) companies used in the sample had typical apparel design and product development challenges and (b) the research sample was a case study and was not generalizable to an apparel manufacture population.

Figure 1 is an illustration of the research boundaries which encompass functional activities, inputs, outputs, controls, and mechanisms of the design, and the product development process. The researcher did not attempt to research the full production process or to implement process improvement of subjects involved in the study.

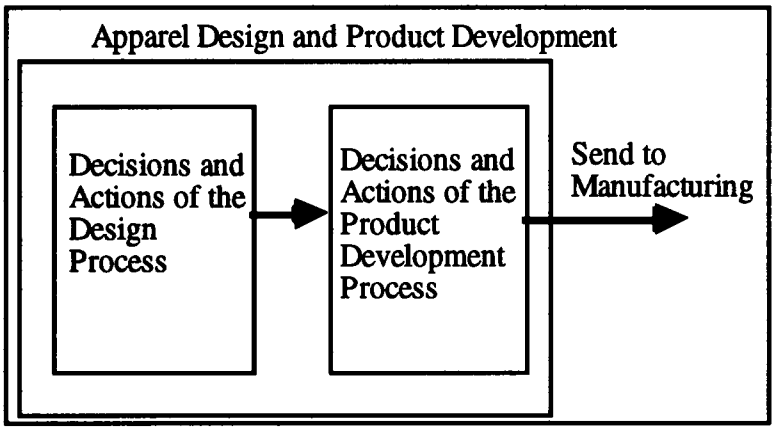


Figure 1. Research boundaries.

Conceptual Definitions

Apparel Product Development Time: Total apparel product development time (e.g., days, weeks) starts with a seasonal line conception and completes with sales samples production. Employees track product development time by using a line development calendar (Glock & Kunz, 1990).

As is Environment: The *as is* environment is the way an organization currently operates. The *as is* environment provides a basis for a researcher to study an organization's

current process to identify repetitive processes that are nonvalue-added (Prasad, 1996).

Concurrent Engineering: This systematic approach to product design is a process that integrates design with related manufacturing and support processes. All elements of product design are considered concurrently including life cycle, quality, cost, schedule, and user requirements (Winner et al., 1988).

Control: A control is a condition or circumstance that constrains a functional activity (Materials Laboratory AF Wright Aeronautical Laboratories, 1981).

Decision Making: An individual evaluates alternatives using a complex cognitive process to select a course of action (Sanders & McCormick, 1993).

Design: Design is a process used to create a change in order to satisfy a want or need (Blaich & Blaich, 1993; Lewis & Samuel, 1989).

Excess cost: Expense that is associated with waste from inventory, complicated manufacturing systems, overhead, rework and operating expenses (Prasad, 1996).

Function: Function is an activity that transforms inputs into outputs (Materials Laboratory, 1981).

Input: Input is information or materials (i.e., data) that is needed to perform a function (Materials Laboratory, 1981).

Integrated Design: A process in which decisions and actions made by a design team for design choices and process capabilities are made early in the product development process (Wheelwright & Clark, 1992).

Mechanism: A mechanism is a person or machine that performs a functional activity (Materials Laboratory, 1981).

Multi-disciplinary Teams: A multi-disciplinary team consists of people from design, manufacturing, marketing, finance, planning, and service departments who work

concurrently to consider costs, quality, schedule, and user requirements (Yannoulakis, Joshi, Sanjay, & Wysk, 1991).

Nonvalue-Added and Rework Stage: An output of a functional activity is classified as nonvalue-added or rework if work existed prior to the functional activity and the work could not go forward without correction (Duffey & Rosen, 1994).

Output: Output is information or material (i.e., data) created when a functional activity is performed (Materials Laboratory, 1981).

Process Delay: A process delay is defined as any activity or group of activities that are created by not staying within a pre-established and designated time allotment (Duffey & Rosen, 1994).

Product Development: The product development process is the set of activities, tools, methods, and procedures that translates customer needs into a product. Design information is used to create, test, and refine a design solution into a manufacturable product in order to meet production requirements (Carter & Stilwell-Baker, 1992).

Q-Sort: A comparative scaling technique that allows a researcher to categorize a large number of objects. The researcher sorts and groups Q-Sort objects based on their similarity with preset research criteria (Malhotra, 1993).

Quality: Quality attributes are categorized into manufacturing quality and perceived quality. Manufacturing quality is defined as design attributes that affect a manufacturing process that will limit scrap, rework, and inspection. Perceived quality is defined as the quality of user-defined performance, service, and maintenance (Duffey & Rosen, 1994).

Sequential Engineering: In this type of engineering process, design, prototype development, production, and distribution are separate sequential functions. The

next step in the sequence does not begin until the previous step is completed (Syan, 1994).

Time-to-Market Delay: A delay of a process can mean that a product will not reach market when expected. Time-to-market delay involves any iteration of design and pre-production activities that have a significant effect on market entry. The delay causes lost revenue due to late entry, opportunity cost loss, or delayed payback for equipment investment (Duffey & Rosen, 1994).

To Be Environment: The *to be* environment is a projected future environment for an organization in which people design a product correctly the first time. The goals of a *to be* environment are to increase throughput, improve productivity, and decrease engineering change orders (Prasad, 1996).

Traditional Design Process: A design creation process that includes problem recognition, problem definition, exploration of the problem, the search for alternatives, evaluation and decision making, specification of solution, and communication of a solution (Lewis & Samuel, 1989).

Acronyms Used in the Study

Acronym	Phrase
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CE	Concurrent Engineering
CERC	Concurrent Engineering Research Center
DFC	Design for Cost
DFET	Design for Enabling Technology
DFLC-I	Design for Life Cycle-Inspectability

(table continues)

DFLC-M	Design for Life Cycle-Maintainability
DFLC-R	Design for Life Cycle-Reliability
DFM	Design for Manufacturability
DFQ	Design for Quality
ICOM	Inputs, Controls, Outputs, and Mechanisms
IDEF	Integrated Computer-Aided Manufacturing (ICAM) DEFinition
$IDEF_0$	IDEF Function Model
QFD	Quality Function Deployment
SBU	Strategic Business Unit

Assumptions

1. The research sample encountered typical apparel industry design and product development challenges.
2. The relationships between the apparel manufacturers and textile suppliers are typical.
3. The functional activity, input, control, output, and mechanism decisions made by apparel industry associates, when interviewed and observed, were typical.
4. The time span in which data were collected was a typical design and product development cycle.
5. Externalities of the research included varying management philosophies and company cultures.

CHAPTER II. REVIEW OF RELATED LITERATURE

Introduction

This chapter describes pertinent information on current U.S. apparel manufacturing challenges and an approach to improve the apparel design and product development process. Since the 1970s, competition from apparel imports has challenged many U.S. apparel manufacturers. Background information provides a description of apparel industry competitiveness, challenges, traditional product development, and sequential manufacturing.

During the 1990s, many apparel manufacturers have emphasized the need to improve the design and product development process. One design and product development improvement approach is concurrent engineering (CE). CE is an approach in which a team of people simultaneously consider all stages of a product's life cycle from conception through disposal. Many durable and consumer goods industries have successfully implemented CE. A review of CE literature shows no applications where CE has been used for apparel manufacture. The chapter concludes with a rationale of why CE is needed for the apparel industry.

State of the Apparel Industry

The Fiber/Textile/Apparel (FTA) complex is critical for the U.S. economy. Standard and Poor's (1996) Industry Surveys of 1,000 leading U.S. companies from 21 major industries reported that 1994 FTA shipments were valued at 111 billion dollars. Moncarz (1992) reported that in 1990 the FTA complex was larger than the automobile, steel, and chemical refining manufacturing industries combined. Nationwide, apparel is a significant portion of the FTA complex as shown by 1994 shipments valued at 81 billion dollars (U.S. Department of Commerce, 1995). Apparel manufacture is extremely

important to the economy of select U.S. regions. For example, in 1996, California apparel sales alone accounted for 19 billion dollars (Young, 1996). In 1992, the FTA complex accounted for 9.4% of U.S. manufacturing employment (U.S. Department of Labor, 1994c). The FTA complex is the first or second largest employer in many southeast states (Redman, Chiappina, & Clausen, 1994). In 1993, the FTA complex accounted for 1.87 million domestic jobs (U.S. Department of Labor Bureau of Labor Statistics, 1994b). The related support industries of textiles and retail accounted for an additional 1.7 million jobs in 1996 ("News Notes," 1996). Although the apparel segment accounts for 50% of the FTA complex employment, it is often called the forgotten industry (Moncarz, 1992).

Even though the overall size of the FTA industry remains large, annual U.S. apparel sales have decreased from 84 billion dollars in 1989 to 73 billion dollars in 1995 (Brown, 1996). U.S. apparel manufacturing employment has decreased from 1.4 million workers in 1973 to 846,000 workers in 1996 ("News Notes," 1996; Standard & Poor's, 1996). In 1995 alone, the U.S. apparel manufacturing sector lost 90,000 positions to foreign countries, a 10% drop in domestic employment (Keenan, 1996; "News Notes, " 1996). If this trend continues, some authorities have questioned whether the U.S. will be able to successfully manufacture its own clothing.

Intense Manufacturing Competition

In the 1990s, survival is paramount to U.S. manufacturing companies that face intense competition (Wheelwright & Hayes, 1991). The U.S. FTA complex has experienced both domestic and international competition in recent decades. U.S. industrial competition has increased due to the (a) threat of new entrants, (b) threat of substitute products or services, (c) bargaining power of suppliers, (d) bargaining power of buyers, and (e) rivalry among industry competitors (Porter, 1990a). This competition is especially strong in industries such as apparel because the industry has easy entrance requirements, high labor intensity, technologically simple machinery, easy access to raw

materials, few capital outlay requirements, and low technical knowledge requirements (Ghadar, Davidson, & Feigenoff, 1987; Jernigan & Easterling, 1990; Standard & Poor's, 1996). For these reasons, the apparel industry is particularly vulnerable to competition from low wage countries. Import penetration has been a serious threat for apparel manufacturers (Standard & Poor's, 1996). In 1994, 40% of the apparel sold in the U.S. was cut and sewn outside the U.S. in lower wage countries. The import trend from low wage countries is expected to continue (Standard & Poor's, 1996) and will have the greatest impact on production positions. Import penetration is lowest for basic apparel products (e.g., jeans) and highest for seasonal (e.g., women's dresses) and private label products (Standard & Poor's, 1996). Some industry analysts speculate that the adverse effect on apparel design positions will be lower than the trend in manufacturing employment and most apparel items will continue to be designed in the U.S. (U.S. Department of Labor, 1994a). Competition, at an all-time high in the U.S. apparel industry, has put tremendous pressure on manufacturers to reduce costs and to increase productivity (Dickerson, 1991).

According to the MIT Commission Report on Industrial Productivity, the U.S. FTA complex faces serious competition, and a crisis prevails in the apparel industry (Commission Working Group, 1989; Willett & Willett, 1992). The primary reasons that U.S. manufacturing industries cannot readily compete are organizational management problems and high manufacturing labor intensity (Wheelwright & Hayes, 1991). Specific management problems are (a) short time horizons for strategic business decisions, (b) insufficient attention to foreign industrial competition, (c) lack of cooperation within and among U.S. companies, (d) focus on minimizing labor costs rather than viewing labor as a productive and evolving resource, and (e) recurrent weakness in technological practices in designing reliable, manufacturable products (Chase & Aquilano, 1992). Management problems can cause failure when managers are not well-versed in their company's

identity, vision, competition, competitive forces, buyout organizational change, and customers (Hammer & Champy, 1993; Labich, 1994). Problems specific to the apparel industry are (a) low capital investment in primary equipment (e.g., sewing machines), (b) high annual turnover and failure, (c) after-tax profits of 1%-2% that are substantially lower than other U.S. manufacturers (Standard & Poor's, 1996), and (d) communication barriers among the segments of the FTA complex due to traditions of autonomy, fierce competition, and suspicion (Moncarz, 1992; Stevens, 1992).

Apparel Manufacturers Resisting Change

Generally, companies that have not recognized their competition as being faster, stronger or more agile have relied on producing outdated models and recapturing the company's past success stories (Labich, 1994). This strategy of "business as usual" has ensured failure for many apparel manufacturers because the combined impact of unstable markets, consumer demand, and technological change can make apparel products obsolete when they reach the market (AAMA, 1984; Nilsson, 1992). Even with the realities of extinction, some apparel manufacturers have resisted change, have emphasized increased productivity through economies of scale, or have focused extensively on reducing direct labor costs (Adams, 1993). Reasons for resisting change include high expense of technology, low return on investment, and changes in managerial positions. The Commission Working Group on the Textile Industry (1989) claims the primary reason for the lack of apparel industry change has been the predominance of small firms with limited financial resources. Moncarz (1992) believes the FTA industrial decline is due to poor communication among the segments of the FTA complex, weak funding support for design research and development, and the inability to deliver what consumers want. Stevens (1992) hypothesized, "Apparel makers have three choices, they can integrate, liquidate or relocate" (p. 30).

The Challenge: Uniqueness of the Industry

The apparel industry faces unique challenges in the manufacture of its product. These challenges include (a) types of raw material used, (b) limits of automated equipment, (c) limits on large production runs, (d) variable product life cycle, (e) high seasonality of product lines, (f) co-location, and (g) dependence on fashion acceptance (Dickerson, 1991; Jernigan & Easterling, 1990). Most production improvement strategies have been difficult for apparel manufacturers to implement because of this product uniqueness.

Type of Raw Materials and Variations

An important aspect of apparel design is the selection of a fabric for a specific garment (Frings, 1994). Many consumers demand innovative fabrics (e.g., microdenier fabrics) for garments (Standard & Poor's, 1996). Apparel designers desire fabric (i.e., raw material) diversity, creating the need for textile manufacturers to produce specific product lines for apparel manufacturers. For example, Dan River Fabrics' typical product line has 2,000 fabric styles (Commission Working Group, 1989). When compared to hard material industries, a wider variety of raw materials are used in apparel manufacture (Taylor, Wilkinson, Gibson, Palmer, & Gunner, 1991). The handling of raw materials becomes more complex with increased variability in sizes, weights, and shapes (Shankar & Jansson, 1993).

Limitations of Automated Equipment

Automation used in hard material industries has limited adaptation to the apparel industry's soft, flexible, and continually changing raw materials (Taylor et al., 1991). Automated equipment for apparel manufacture has two limitations: lack of sensitivity for material handling and lack of flexibility for style change. Robotic equipment, used in the assembly process, has had problems in manipulating single-ply fabric and has limited capability for entire-garment assembly (Dickerson, 1991). Bottom weight fabric (i.e.,

pant fabric) tends to be more adaptable to automated equipment than top weight fabric (i.e., blouse fabric) (Standard & Poor's, 1996).

Automated apparel equipment is designed to produce a standardized product and is most adaptive to garments with little or no style change (Solinger, 1988); however, variable market trends require flexibility in automated garment assembly systems (Taylor et al., 1991). Most automated sewing equipment has pre-set dies that are specifically for one size garment component. The dies are not adjustable, and additional dies are required to sew each additional style. For example, if a fashion trend dictates that a pocket component change slightly in size (e.g., 1/4" larger or 1/4" smaller), many automated pocket setters cannot handle the pocket change without expensive capital outlay for new dies and machine retooling. Many apparel manufacturers have continued to use the more labor-intensive method of manual pocket setting to maintain flexibility (T. McClure, personal communication, February 1994).

The capital outlay needed for automated equipment often is not justified by the short demand for fashion products (Dickerson, 1991). An apparel manufacturer may need to use outside contractors to quickly expand or reduce its production output to meet variable market trends and respond quickly to consumer demand (Standard & Poor's, 1996). Consequently, apparel manufacture is predicted to be less automated than most other U.S. manufacturing industries (U.S. Department of Labor, 1994a).

Limitations on Large Production Runs

The apparel industry traditionally sells products to retailers on a seasonal basis: spring, summer, transition or early fall, fall, and holiday. This market system demands that production lines change a minimum of five times annually. Pressure from large retailers for increased new styles creates a need for additional line releases for new products within a season. The demand for more new styles has increased market changes to six or more times in one year. Monthly shipments of new products are common for

Quick Response programs (Frings, 1994; Jernigan & Easterling, 1990). Long production runs are inadequate to meet this market.

Fluctuating market trends require flexible production. Apparel manufacturers continually adjust product lines across seasons for diversity in construction techniques, garment style variation, and variable material types (Dickerson, 1991; Taylor et al., 1991). Staple goods apparel products (e.g., sweatshirts) and seasonal apparel products (e.g., dresses) have different manufacturing requirements (Glock & Kunz, 1990). Staple goods apparel manufacturers focus on low cost and fast production (Moncarz, 1992) and tend to be highly automated with long production runs (Standard & Poor's, 1996). Seasonal apparel product needs depend on consumer desires for uniqueness and style changes (Moncarz, 1992). The demand for frequent style changes limits the effectiveness of economies of scale gained through large standardized apparel production (Dickerson, 1991).

Variable Product Life Cycle

Apparel product life cycles vary depending on whether they are fashion apparel products or basic apparel products. Fashion products have frequent garment style changes and comprise 80% of the apparel market. Basic apparel products have few garment style changes and make up 20% of the apparel market. Average retail product life cycles are 10 weeks for high fashion products, 20 weeks for fashion products, and 52 weeks or year round for basic products. Varying product life cycles create different production challenges for apparel manufacturers.

Response to consumer demand can challenge apparel manufacturers as consumer interest changes quickly (Dickerson, 1991). Jernigan and Easterling (1990) noted that consumer expectation of an apparel product's life cycle varies with product type, consumer's age, and expected product use. Prediction of product quantities is harder for apparel manufacturers of fashion women's apparel than of men's apparel or commodity

apparel (Standard & Poor's, 1996). Some apparel products (e.g., a cashmere cardigan sweater) are expected to last for many years and may be considered fashionable for many years. Other fashions (e.g., holiday sweaters) are expected to last for one season (Jernigan & Easterling, 1990). Many times apparel products fashionable one year are not fashionable the next year (Frings, 1982).

An additional challenge for apparel manufacturers is the high dependency among apparel marketing channel members (Dickerson, 1991). Some fashion items with short life cycles put a high demand on an input (e.g., a specific stylized fabric) and may create an out-of-stock situation in the wholesale market. For example, short retail life cycles of fashion apparel products create difficulty for U.S. manufacturers that contract cut and sew production overseas and because the shipping time can exceed the length of the product life cycle (Standard & Poor's, 1996). The result is lost sales potential (C. Martin, personal communication, August 1994).

High Seasonality of Product Lines

Change continues to be the essence of fashion (Peters, 1992). Compared to other consumer goods, the majority of apparel products have short selling seasons, and some fashion characteristics (e.g., color, texture) endure only one season (i.e., less than three months) (Jernigan & Easterling, 1990). Some apparel products (e.g., swimsuits) historically have very short selling seasons that cause extreme peaks and valleys in production. To balance seasonal demand with production lines, some apparel manufacturers produce dissimilar products such as swimsuits and backpacks. This variability is challenging for apparel manufacturers, because sewing dissimilar products requires a change in equipment and plant layout (T. Harris, personal communication, August 1994).

Co-location

The U.S. fashion center is New York City. Often, apparel designers, sales showrooms, and marketing offices are located in New York City (Jernigan & Easterling, 1990), and company headquarters and manufacturing facilities are located in other regions of the U.S. (Dickerson, 1991). Corporate headquarters for apparel companies are spread throughout the U.S., while the majority of domestic manufacturing is located in eight states: Alabama, California, Georgia, New York, North Carolina, Pennsylvania, Tennessee, and Texas (U.S. Department of Labor, 1994a). As with other U.S. industries, apparel companies experience miscommunication when product designers are isolated or physically removed from company headquarters (e.g., co-location) (Crawford-Mason, 1994) or manufacturing facilities (C. Hinson, personal communication, February 1994).

In the 1980s and 1990s, many organizations moved towards an open environment to bring employees physically together in the same facility. The open environment allows company employees to personally communicate with upper management, product designers, manufacturers, engineers, and other personnel (Cedrone, 1994; Crawford-Mason, 1994). Apparel designers physically located at manufacturing facilities tend to be more accountable for designs produced than designers who are not located at company headquarters (F. Penman, personal communication, August 1994; T. Burg, personal communication, May 1994). The move toward an open environment has been adopted by a few apparel manufacturers such as London Fog (Cedrone); however, co-location and separation continue to exist for many apparel manufacturers.

Hammer and Champy (1993) note that computers can provide more communication across distances, but if companies do not change the way a job is done, organizations do not improve their business processes. In fact, the processes can further deteriorate. A lack of process improvement was noted by a pattern maker with the introduction of electronic communication (i.e., facsimile) between co-located apparel

designers and production pattern makers (C. Hinson, personal communication, February 1994). From the pattern maker's perspective, rather than improving communication, the facsimile has created urgent situations and excuses for a lack of planning.

Dependence on Fashion Acceptance

Many apparel associates employed by apparel manufacturers spend time reviewing high fashion design for style and color direction in their line. This process is followed because the fashion acceptance theory states that fashion is first adopted by wealthy and influential individuals and is later adopted by the mass public (Frings, 1994). This is a time-consuming process that creates delay time in the development of new fashion items and tends to reduce variability of design.

Recently, the use of the fashion acceptance theory to direct design has been criticized. This method of fashion design is no longer effective. Vogue editors ("Is fashion...," 1995) interviewed leading international apparel designers, asking if fashion designers were out of touch with today's consumer and whether the fashion industry was pushing for too much change. Bill Blass commented that today's consumer does not care about fashion trends. Standard and Poor's (1996) indicated that during the 1990s, women's high fashion designers have failed to introduce any influential trends. Numerous world changes have lessened the influence of high fashion designers, and today's U.S. consumers tend to wear comfortable apparel. Apparel manufacturers must develop products that meet their consumer market (Frings, 1994) rather than rely on fashion forward influences.

Why the Apparel Industry Needs to Change

Competitiveness is a driving force for industrial change (Porter, 1985) and textile and apparel companies must change in order to survive (Berkstresser & Buchanan, 1986). In the 1980s, predictions for the future of FTA in the U.S. were that domestic apparel manufacture would decrease to zero by the year 2000 if import penetration continued at

the same rate as it had during the decade from 1975 to 1985 (Commission Working Group, 1989). U.S. apparel manufacturers that wished to remain in business had to effect radical change to move from mere survival to competitiveness (Berkstresser & Buchanan, 1986). Weston (1990) described competitiveness as a company's response to customers, its ability to deliver on time, its willingness to adjust to changing market requirements, and its ability to work effectively with vendors and subcontractors.

The apparel industry's emphases in the 1980s were adoption of new technology, manufacturing process efficiency, material utilization, and material flow (Berkstresser & Buchanan, 1986; Ghadar et al., 1987; Govindaraj, 1991). Caught between Industrial Age production methods and the knowledge-based information age, apparel manufacturers are at various stages of transforming their manufacturing practices in the 1990s. Some manufacturers with large production volumes are using advanced manufacturing technology; however, the high initial capital investment (e.g., an automatic cutter can cost approximately $1,000,000) restricts manufacturers with low production volumes from investing in technology (Commission Working Group, 1989; Standard & Poor's, 1996).

While it is essential for companies to be fast and efficient, this strategy alone is not enough (Wheelwright & Clark, 1992). New technological adoption has been ineffective when used within existing corporate structures (Syan, 1994). Changes must reach beyond simple technology adoption. The Commission Working Group on the Textile Industry (1989) recommended that the FTA complex manufacturers adopt new technologies and better linkages with customers and suppliers. Competitive benefits from a combination of new structures, new business practices, and new technologies in the apparel industry include reducing labor costs, enhancing product quality, and enhancing process flexibility (Berkstresser & Buchanan, 1986).

In the 1990s, the rules of the game have changed for every business (Labich, 1994) even the apparel business (Black, 1994). Market growth, customer demand,

product life cycles, and competition are no longer constant and predictable (Hammer & Champy, 1993). Long production runs of staple products are no longer profitable and often not salable. Manufacturing companies must find new ways to satisfy changing markets and new strategies to develop competitiveness (AAMA, 1994). Success in the 1990s is dependent on an organization's vision, strategy, and action implementation (Sink, Morris, & Johnson, 1995).

How Apparel Manufacturers Should Change

To be more competitive, the U.S. apparel industry is compelled to develop new industry paradigms that integrate past knowledge with present technologies. As an example, the paradigm of designers operating in isolation from the manufacturing process is detrimental to apparel manufacturers. The industry must develop a paradigm that blends design with manufacturing, and that provides a product or service with the most value and within the least amount of time (Carter & Stilwell-Baker, 1992). For success, apparel companies must (a) reevaluate traditional ways of conducting business by considering new products, production systems, and distribution options; (b) invest in new technology; (c) consider new business strategies; and (d) respond to market changes by forming better alliances with suppliers and customers (Black, 1994). The Commission Working Group on the Textile Industry (1989) recommended that companies emphasize investment in research and development, re-envision corporate strategies, remove communication barriers, and use back-to-basics production operations.

In order for apparel manufacturers to evaluate the traditional ways of conducting business and to welcome new strategies, executives need to develop an approach to determine how the company needs to change. One approach is to evaluate a company's *as is* (i.e., current) environment to decide what and how the company needs to improve. A company's *as is* environment evaluation is a starting point for apparel manufacturers to assess and develop a *to be* (i.e., improved) environment (Jayaraman, 1990).

Process Capture: The *As Is* Environment

To improve competitive advantage, a company must first assess its current situation (Carter & Stilwell-Baker, 1992). The Concurrent Engineering Research Center (1992) defined process capture as the documentation and verification of an organization's *as is* (i.e., current) environment. This documentation of the *as is* environment is necessary in understanding a process and is a major step in design accountability and process improvement identification (Pawar & Driva, 1996). Management and improvement of a business process is possible only with the accurate capture of the *as is* environment (Pawar & Driva, 1996).

Traditional *As Is* Production Process: Sequential Manufacturing

The apparel industry has operated as a traditional mass market industry (Commission Working Group, 1989). Sequential manufacturing is the traditional production method used in the manufacturing of goods (Syan, 1994) and historically has been used for apparel and textile manufacture (Amacher et al., 1991; Willett & Willett, 1991). Each stage, taken in turn, requires that the next step in the sequence does not start until completion of the previous step. This process is commonly called the *over the wall* approach. In sequential manufacturing, design operates in relative isolation. The result of the process is that decisions made by designers in the conceptual design stage often produce undesirable effects on later processes. This situation requires product redesign and return to previous stages for corrections. The return to previous stages causes delays and increases costs (Menon, 1992a; Syan, 1994).

The apparel industry traditionally has used the sequential manufacturing process shown in Figure 2. The functional areas of design, prototype, production, distribution, and sales are separate and sequential functions. As with other sequentially engineered processes, the apparel design process is generally isolated from production. A feedback

loop exists only between apparel design and early prototype development functions (e.g., patternmaking).

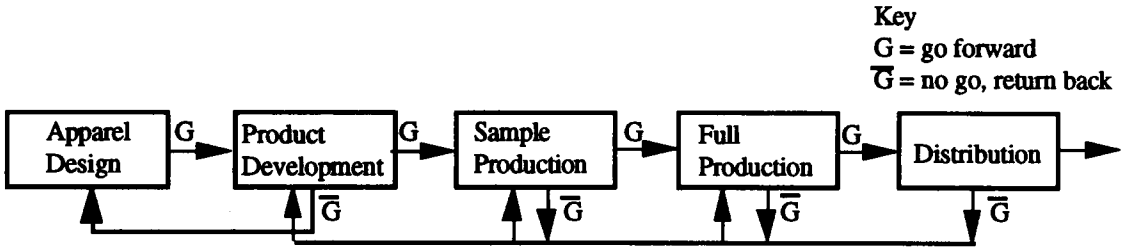


Figure 2. Traditional apparel manufacturing process.

Limitations of Sequential Manufacturing

Limitations of sequential manufacturing are that: (a) the process is time-consuming and expensive, (b) the design decisions stage often has detrimental effects on production processes, requiring product redesign, and (c) product design is not integrated with and is isolated from the manufacturing processes (Cleetus, 1992; Menon, 1992a). Manufacturing competitiveness and the use of efficient, operational technologies have lessened advantages gained from mass manufacturing (Committee on Analysis, 1991; Hynynen, 1992; Moncarz, 1992). Increased competition has required manufacturers to use cost-efficient, flexible manufacturing systems that produce reliable, high quality, well-designed products in less time for lower prices (Committee on Analysis, 1991; Crow, 1992; Hyeon et al., 1993). However, traditional mass market companies are challenged by a pull-through approach where customers dictate needs on products, price, and quality (Hammer & Champy, 1993).

Traditional *As Is* Design and Product Development

The design and product development processes traditionally have been separate functional areas and have operated in isolation from other business activities (Wheelwright & Clark, 1992). This section describes the generic, traditional design and

product development process, the apparel design process, and the traditional apparel and textile product development process.

Engineering Design Process

Design is a process used to create a change in order to satisfy a want or need (Blaich & Blaich, 1993; Lewis & Samuel, 1989). A designer's primary design objective is to restructure complicated decisions into simple ones. Design is the first step in the manufacturing process. Upon design completion, product design concepts are forwarded to product development, manufacturing, and quality and service functions (Fitzsimmons, Kouvelis, & Mallick, 1990; Syan, 1994).

To create product designs, some individuals use a systematic decision process. The foundation of this approach is engineering design process theory (Jones, 1992). Wilcox (1987) describes engineering design as the creative process of identifying needs and developing a product to meet those needs. The design process does not have a single correct route; rather, for a designer to answer a design problem, he/she has a target goal. The design process is not described as sequential, but is an iterative process in which the designer returns to previous design phases to refine and improve the design. Design success is attributed to a designer's ability to identify and control the boundaries of a design problem (Medland, 1992; Middendorf, 1969).

In engineering design process theory, individual activities are grouped into global headings that include (a) problem recognition, (b) problem definition, (c) problem exploration, (d) alternative search, (e) evaluation and decision, (f) solution specification, and (g) solution communication (Leech, 1972; Lewis & Samuel, 1989; Medland, 1992; Middendorf, 1969).

Regan, Kincade, and Sheldon (in press) identified actions and decisions made during the apparel design process that apply to the engineering design process. Specific apparel design activities were then correlated with the specific phases of engineering

design process theory. The following is a summary of the Regan et al. (in press) results. During the problem recognition stage, apparel design associates focused on customer loyalty, design concept difficulty, and idea initiation. Apparel design associates focused on the establishment of apparel line objectives, resource identification, and design boundaries during problem definition. Design associates used a multitude of design inputs that included wholesale market search, retail market scan, competition assessment, idea creation, design strategy development, and customer objective establishment. During the search for an alternatives phase, apparel design associates made early evaluations of designs based on their design experience, market service provision, and prior product successes and failures. The design apparel associates edited the merchandise line many times during the evaluation and decision phase. During the solution specification phase, design apparel associates evaluated design concepts and the apparel line to ensure that the designs met market needs and sales potential. In the solution communication phase, apparel design associates evaluated apparel lines for line relationship and finalized the merchandise line. Apparel design associates communicated the solution by presenting the apparel design concepts at company meetings (Regan et al., in press) (see Appendix A for published dissertation articles).

As Is Sequential Product Development

Product development is a common process found in most companies (Hammer, 1996). The product development process is the set of activities, tools, methods, and procedures that translate customer needs into product designs. During product development, individuals translate, test, and refine design inputs to create a product that will meet production requirements (Carter & Stilwell-Baker, 1992). Product development affects manufacturing processes: the failure to detect a problem early on can affect the entire manufacturing process (Esch, 1991). Product designing and developing influences business processes, including market analysis, materials procurement, product cost

estimation, assembly, inspection, service, product maintenance, and disposal (Hyeon et al., 1993).

Sequential textile product development. Although textiles and apparel are interdependent, the textile and apparel product development processes are separate functions, often performed by separate companies for a single product. The traditional textile product development process includes market research, prototype development, prototype evaluation, performance testing, and product modifications (see Figure 3). Market research includes identification of target market fashion trends and consumer product expectations. Prototype development entails developing fashionable fabrics in customer-requested fiber blends, finishes, and fabrications. Prototype evaluation consists of giving sample cuts to apparel designers to evaluate desired fabric characteristics (Frings, 1994). Common textile performance tests include tensile strength, abrasion resistance, washability, and comfort. Apparel product testing includes consumer wear tests (Kadolph, Langford, Hollen, & Saddler, 1993).

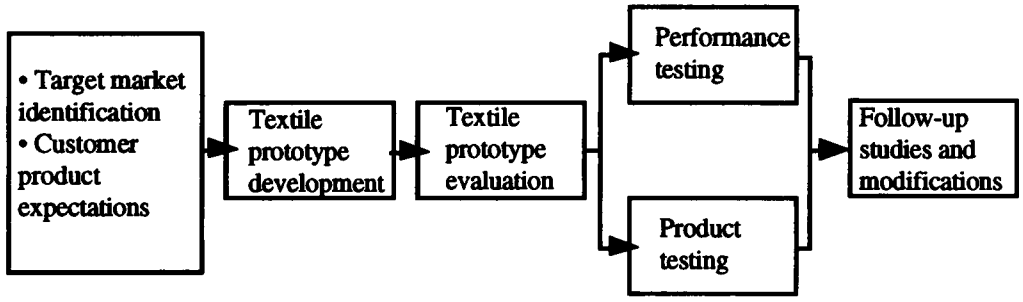


Figure 3. Sequential textile product development (adapted from Kadolph et al., 1993).

Sequential apparel product development. The apparel product development in sequence includes (a) line plans, (b) line plan summary, (c) product development, (d) line preview, and (e) line release (See Figure 4). A line plan includes information gathering for fashion scope, market information, and past line sales. During the line plan summary, apparel designers and merchandisers analyze information from line plan development.

Line preview includes budget plans, style evaluation, and sample making. The target date for showing the line to retail buyers is part of the line release (Glock & Kunz, 1990).

LINE PLAN	LINE PLAN SUMMARY	PRODUCT DEVELOPMENT	LINE PREVIEW	LINE RELEASE
• Idea initiation • Apparel line objectives • Design inputs: markets shopped fashion direction • Fabric selection • Review of current markets • Assessment of competition • Past performance evaluation • New idea development • Color selection	• Season framework development • Parameter development (SKU, fabrics, colors, styles) • Design evaluation • Line development • Materials & production sourcing • Line relationship • Line evaluation • Line presentation	• Design submission • Engineering evaluation • Pre costing of garments • Construction quality specifications • Final costing of garments • Advance manufacturing specifications • Advertising review • Apparel line review	• Planning sessions for: • Line review • Editing of line • Budget • Evaluation of styles for sales potential and cost effectiveness • Evaluation of prototype garments	• Target market release date • Sales meeting • Road samples completion • Modifications of garments based on retail buyers and sales representatives opinions on market potential

Figure 4. Sequential design and product development (adapted from Glock & Kunz, [1990]; Regan et al., in press).

Problems with sequential design and product development. Sequential design and product development are problematic. Problems that occur are often associated with a designer's attitude of design it now, fix it later (Blanchard et al., 1995). The creation of poor designs is due often to a designer's lack of knowledge about manufacturing processes (Hayes, Desa, & Wright, 1989). Often, products are designed multiple times: the original design and a redesign that incorporates product changes, which adds expense to the process. The cost of changing a design is minimal in the design concept and design development stages. As a design moves closer to the production stage, the cost of changes becomes more expensive. Most design changes occur at the end of a project, which is the most expensive time for change (Menon, 1992b).

In the 1990s, competitiveness is changing from being a cost-efficient approach to a time-based approach (Committee on Analysis, 1991). In competitive climates with

rapid change, development time has become critical (Carter & Stilwell-Baker, 1992). Time to develop and introduce new products has decreased and at the same time the length of product life cycles has diminished (Shina, 1991). Slow processes, such as sequential manufacturing, have increased the need to improve the product development process and to shorten product development cycles (Committee on Analysis, 1991; Hammer, 1996). Some Japanese industries have concentrated on shortening product development time since the mid-1980s. The primary reason for this emphasis is that most of the profit made from a successful product is realized when the product is first introduced (Shina, 1991). Some U.S. apparel manufacturers in the 1990s are recognizing the need to improve the product development process by reducing the time from design through retail store delivery (Standard & Poor's, 1996). Textile companies are trying to shorten the typical five-year lead time to enable them to react faster to consumer demands (Frings, 1994).

Process Capture: Creating a *To Be* Environment for Competitive Advantage

Kasten (1991) reported that, to meet customer needs, apparel companies need to gain a competitive advantage. The need for companies to attain a competitive advantage is well documented by Porter's (1985, 1990a, 1990b) four-year study on patterns of industrial success within 10 industrial countries. Competitive advantage is achieved through the way firms choose and implement specific strategies of designing, producing, marketing, delivering, and supporting products. One way companies achieve competitive advantage is through innovation. Innovation tends to be accomplished with incremental change through new product design, production process, market segment focus, or employee training (Porter, 1990b). For example, textile manufacturers could obtain a competitive advantage through implementing innovative processes through Computer-integrated Manufacturing (CIM) (Esch, 1991). Levi Strauss & Company design and

manufacture of custom-size jeans exemplifies an apparel manufacturer's use of innovative competitive advantage strategy. The custom jeans are offered to customers with a fast turnaround time for a slight price increase of ready-to-wear Levi's (D. Heninricks, personal communication, January 1996).

Types of Competitive Advantage

Competitive advantage strategies using innovation are classified as lower order or higher order strategies. A lower order competitive advantage strategy may be used when a company wants to gain entrance to a new market but is easy for competitors to emulate. A higher order competitive advantage strategy is more difficult for competitors to emulate and is frequently used when a company desires to develop sustainable competitive advantage. Sustainable competitive advantage is achieved if a company succeeds for a greater length of time than its competitors. The keys to sustainable competitive advantage are for a company to: (a) adopt a global approach, (b) constantly improve and upgrade existing company competitive advantages, and (c) continue to innovate (Porter, 1985; 1990b). Hammer and Champy (1993) noted that "Today's companies must move fast, or they may not be moving at all" (p. 23). Companies that stop improving and innovating will be overtaken by competitors (Porter, 1990b).

Competitive advantage strategies can also be classified as cost leadership, differentiation, and focus strategies (Porter, 1990a). Porter (1985) defined cost leadership as the position when a firm designs, produces, and markets comparable products more efficiently than its competitors. Cost leadership is acquired through the use of cheap raw materials or low labor cost. Cost leadership is a lower order competitive advantage, and competitors can readily nullify the advantage gain with this strategy. Many apparel manufacturers have focused on cost as a competitive advantage. The primary emphasis has been to reduce labor content and increase economies of scale (Adams, 1993). The

American Apparel Manufacturers Association (AAMA) (1994) advocated that it is no longer viable for apparel manufacturers to focus only on low cost leadership.

Differentiation is a more stable form of competitive advantage strategy than cost strategies. Through the use of process technology, differentiation is the ability to provide unique and superior value to buyers in terms of product quality, special features, or customer relations (Porter, 1990a). Differentiation allows a firm to command a premium price, which can lead to superior profits (Porter, 1990a). In apparel companies, differentiation can be achieved with brand development, special color selection, or specialized apparel features. For example, Patagonia offers many specialized exercise and sport apparel products. One specialized Patagonia apparel product is a fisherman's vest specifically designed with garment styling, pockets, and fasteners designed for ease of use (K. Larramundy, personal communication, July 1994).

Focus is a higher order competitive advantage strategy and is achieved when a firm emphasizes differentiation strategies for a narrow industry segment (e.g., specialized or innovative products). Focus can be used to create competitive advantages and may assist companies to address a new market opportunity or serve a market segment that other companies have ignored (Porter, 1990a). Gruppo Finaziario Tessile, an Italian garment manufacturer, has achieved competitive advantage through a focus strategy of successful niche by marketing ready-to-wear collections for high fashion designers (Commission Working Group, 1989). The focus strategy assists companies to sustain their competitive advantage positions.

Design and Product Development Competitive Advantage

Blaich and Blaich (1993) predicted that innovations in product design will be the next industrial competitive advantage strategy. International competition, market segment explosion, market niche development, and accelerated technological changes have made the development of new products and new processes imperative (Wheelwright & Clark,

1992). For example, competition was the motivating factor for some textile companies to create new textile products such as Lycra and GoreTex during the 1980s (Ghadar et al., 1987).

The design of products needs to be considered as a strategic activity and given the same attention that companies place on the strategic issues of price, quality, time-to-market, and technological innovation. Company executives initiate a design competitive advantage when the company's strategic plan commits to offering superior products with high quality, reliability, and service and delivery (Fitzsimmons et al., 1990). Often, consumers are overloaded with available product choices (Peters, 1992). From the consumer's viewpoint, product, price, and quality are often equal; therefore, product design is the single element that differentiates one product from another. A company's product design strategy is important to ensure product differentiation (Blaich & Blaich, 1993; Fitzsimmons et al., 1990). In apparel, a product design strategy has been a success factor for some apparel manufacturers. Some long-lasting, successful apparel product design strategies are Levi Strauss & Company jeans designed in the 1890s and Wrangler's jeans designed by Rodeo Ben in the 1940s. In the 1980s and 1990s, some successful product design strategies are Ralph Lauren's polo pony icon, Liz Claiborne's casual comfortable dress, Nautica's nautical theme merchandising, and Donna Karan's tailored business dressing (Agins, 1994; C. Kumiega, personal communication, February 1996).

Design and product development control and impact production. Early design decisions have a significant effect on product manufacturability, quality, cost, introduction time, and potential market success (Hyeon et al., 1993). The design process accounts for only 5% of product cost; however, it controls 60% to 95% of total cost (Syan, 1994). To attain a design competitive advantage, companies should (a) shorten the time between conception and new product introduction in the market, (b) match target

customer expectations, (c) respond to customer needs quickly, (d) increase productivity, and (e) create products that are distinctive (Carver & Bloom 1991; Wheelwright & Clark, 1992).

Competitive advantage is exemplified by the activities of the Italian footwear industry. From the 1940s, Italian shoe manufacturers have developed a unique infrastructure between footwear suppliers and footwear manufacturers. During the conceptual design stage, shoe leather manufacturers communicate strategies for new styles, innovative manufacturing techniques, and new textures and colors. To plan new products, leather manufactures obtain early fashion trend information from shoe manufacturers. The rapid pace of new product development provides Italian consumers with product diversification and high product quality (Porter, 1990b). For apparel manufacturers to achieve this competitive advantage, managers and employees need to study organizational structures, responsibility allocation, teams, and employee roles (Adams, 1993).

Implementing Competitive Advantage Organizational Change: Business Process Reengineering

Some companies have found that traditional ways of conducting business are not conducive to achieving a competitive advantage strategy (Montgomery & Porter, 1991). To achieve competitive advantage often requires leadership and organizational change to coordinate company policies, goals, and business plans (Porter, 1990b). To achieve competitive advantage, many companies have reengineered their business processes. Through reengineering, organizational change can include department consolidation, management authority redefinition, and labor relations change (Hollyman & Howie, 1994).

U.S. textile and apparel manufacturing competitive advantage has declined since the late 1960s (Ghadar et al., 1987). As one response to increasing competitive

advantage, some apparel and textile manufacturers have reengineered their business processes (Hammer, 1996; Sprinkle, Charles, & Chepaitis, 1992). Reengineered apparel companies include Columbia Sportswear, Levi Strauss, Cross Creek Apparel, Champion Activewear, and London Fog (Cedrone, 1994; D. Heninricks, personal communication, January 1996; M. Johnson, personal communication, October 1994; Prentice, 1994; S. Smith, personal communication, October 1994).

Reengineering is "the fundamental rethinking and radical redesign of business process to achieve dramatic improvements in critical contemporary measures of performances such as cost, quality, service, and speed" (Hammer & Champy, 1993, p. 32). Reengineering efforts encompass widespread organizational issues that fundamentally change a company's staff, policies, procedures, facilities, and support technologies. Reengineering is an umbrella strategy involving issues that change a company's mission and establish business processes to create value for customers, superior performance, and a superior environment (Hammer, 1996).

Reengineering changes employees responsibilities from a task orientation to a process orientation. Task orientation is performance of a unit of work (e.g., order entry) and process orientation is performance of a related group of tasks (e.g., order fulfillment) (Hammer, 1996). In reengineering, integrated processes replace old functional departments by organizing work around a team. These process changes are designed or reengineered by a group of people who have the skills to handle and process an order (i.e., case team). People communicate with whomever they need rather than work through executive protocol (Hammer & Champy, 1993). Employee empowerment is essential to reengineering, because decision making becomes part of work.

Success of reengineering is measured by customer evaluations (Hammer, 1996). Characteristics that make reengineering efforts successful include (a) deriving objectives directly from business strategy, (b) ensuring commitment from senior management, (c)

identifying and understanding paradigm shifts, (d) focusing clearly on business results instead of business activities, (e) improving continually, (f) implementing change that originates from top management, and (g) integrating change throughout the entire organization (Hollyman & Howie, 1994). During reengineering, a company's activities are changed to create new end results and potential value for a company's customers. Nonvalue-added activities, such as multiple versions of the same process, are company functions that are not valuable to a customer. The nonvalue activities are identified and reduced through reengineering.

Reengineering failure is due to lack of management support and bad company practices (Champy, 1995). Lack of management support includes (a) a lack of commitment and an expectation of instant results, (b) a narrow definition of reengineering, (c) a senior management decision(s) that establish unclear or unrealistic objectives, (d) a problem with management and employee communication, and (e) an existing corporate culture with management attitudes that prevent change. Bad business practices are (a) a need to fix an old process rather than change the process, (b) an incremental versus a radical process redesign, (c) a lack of financial resources to reengineer, (d) a disjointed implementation, and (e) an inconsistent follow-through of process (Champy, 1995; Hollyman & Howie, 1994; Rapoport, 1994). In reengineering implementation, work is organized around processes and teams, decision making is encouraged at the lowest possible level, and emphasis is placed on understanding marketing channel customers and end-use consumers. Reengineering means improvement of business processes, change in the organizational structure, and empowerment of the employee (Hammer & Champy, 1993). Competition has necessitated the reengineering of product development from a task orientation to a process orientation.

Proposal for the *To Be* Environment: Concurrent Engineering

Reengineering is a broad strategy encompassing organizationally-wide issues that change all aspects of how a company operates. In order to be competitive, some companies have focused on improving (i.e., reengineering) product development (Hammer, 1996). Improving product development focuses on integrating design with product development (Wheelwright & Clark, 1992). One approach to improving the design and product development process is through concurrent engineering (CE).

Concurrent engineering is an approach in which a team of people simultaneously considers all stages of a product's life cycle from conception through disposal. It is an implementation approach that emphasizes the integration and management of the design and product development process (Menon, 1992b). According to the Institute for Defense Analysis,

> Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle, from conception through disposal, including quality, cost, schedule and user requirements (Winner et al., 1988, p. 11).

Although the most common term used in the literature is concurrent engineering, similar constructs include integrated product development, simultaneous engineering, life cycle engineering, parallel engineering, team engineering, or concurrent design (Carver & Bloom, 1991; Chase & Aquilano, 1992; Menon, 1992b). The CE approach requires a design team to have early involvement in the design and production stages. The early involvement allows the design team to create a product that is lower in cost, higher in quality, more reliable, and more stable (Talukdar & Fenves, 1989). The use of teamwork

improves the balance among market, design, and production requirements (Carver & Bloom, 1991; Menon, 1992b; Talukdar & Fenves, 1989).

The origin of one component of CE, design for manufacturability, was introduced 180 years ago by Eli Whitney for gun manufacture (Bralla, 1996). Concurrent engineering, as a discipline, was introduced early in the twentieth century. In 1924, Chrysler Corporation's founder pioneered design teams with marketing, finance, and manufacturing representation. In the 1930s, Ford Motor Company's founder supervised multi-discipline design teams. Components of CE, including design for manufacture and design for assembly, were used during World War II by the Ford Motor Company's military transportation division. The accepted historical marker for CE use is Lockheed Aircraft Corporation's Skunk Works project during the 1940s. CE design team use disappeared after World War II and did not reappear until 1979, when it was used again by the Ford Motor Company to design the Taurus and Mercury Sable automobiles (Ziemke & Spann, 1993).

Many industries have experienced success through CE implementation (Janson & Lundborg, 1992; Perry, 1990; Rosenblatt & Watson, 1991). For example, the durable goods industries of aerospace and construction equipment have used CE. Consumer goods industries, including electronics, automobiles, sewing machines, and telecommunications, have also implemented CE (Rosenblatt & Watson, 1991). Reported benefits of CE are reduced development time of 30% to 50%, improved quality of 100% to 600%, reduced costs from 30% to 85%, fewer defects, reduced amount of scrap by 75%, and reduced rework time of 75% (Lawson & Karandikart, 1994; Winner et al., 1988).

Some companies that have shortened product development time through successful CE implementation include Hewlett-Packard, Husqvarna Sewing Machines, International Telephone and Telegraph, John Deere, Kodak, Rolls Royce, and Xerox.

With CE practices, Hewlett-Packard used multi-functional teams to shorten product development time (Rosenblatt & Watson, 1991; Syan, 1994). Husqvarna Sewing Machine company achieved a 30% reduction in total assembly time through the implementation of CE (Janson & Lundborg, 1992). Product cycles were reduced from eight years to three years during Xerox's Express Project implementation. Consumers and individuals from research, development, manufacturing, and marketing were involved in each stage of the design and manufacturing process (Perry, 1990). Kodak implemented CE in the development of the single-use camera, reducing time from concept to production by one-half, and lowering tooling and manufacturing costs (Hammer & Champy, 1993). The John Deere company reduced development time by 60% and reduced new equipment costs by 30% (Rosenblatt & Watson, 1991). Both the Boeing and McDonnell Douglas companies reduced manufacturing costs and inspection costs through CE use (Syan, 1994). The success other industries have experienced with the adoption of CE into their manufacturing process (Rosenblatt & Watson, 1991) warrants consideration for the manufacture of apparel products.

Concurrent Engineering Design Process

CE is an integrated design approach that includes decision making on product function, use, manufacture, maintenance, and disposal (Menon, 1992a). The CE approach contrasts with sequential manufacture, as shown in Figure 2, because the design process is integrated with product development. CE focuses on creating integrated designs with a purpose. Stated advantages of integrated design are the combination of design choices with process capabilities early in the product development process (Wheelwright & Clark, 1992). A design team considers product design choices with process capabilities in a timely and effective way when implementing integrated product development (Blaich & Blaich, 1993; Wheelwright & Clark, 1992). Integrating design with product development requires the use of multi-disciplinary teams from many functional areas so

that early and continuous product design decisions may be obtained from market research through market launch (Blaich & Blaich, 1993).

Design process integration is exemplified in Turino's (1992) CE design process model (see Figure 5). The goal of Turino's CE design process model is to show that design activities are central to a manufacturing process. Manufacture, test, quality, and service functions are shown as design support activities. During the design phase, the design team requires information for manufacture and material specifications. The integration of design, production, and selling of a product enables design to attain information directly from retail customers and, ultimately, consumers. The integrated concepts presented in Turino's design process model are supported by Willett and Willett (1991), who are National Science Foundation (NSF) grant recipients for proposing the need to integrate the design with apparel manufacture.

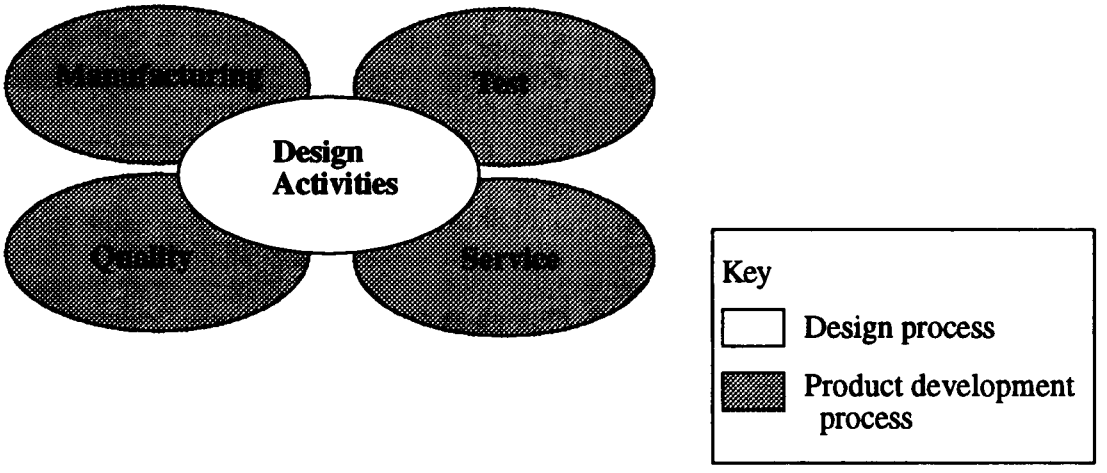


Figure 5. Concurrent engineering design process (adapted from J. Turino, 1992, p. 69).

The ideal time for product change is during concept and design development, rather than close to or during production (Menon, 1992b). In the CE design process, the design team pushes decisions to be made as early as possible by using a concept called a design maturity curve. O'Brien and Smith (1994) defined design maturity as the time when a design is complete or mature enough to be released to downstream activities. The

point of release is when another activity becomes dependent on the current activity; hence, product development activities occur at the point of release. Design maturity lengthens the design process so that a multi-disciplinary design team can concurrently address design of products and their related processes issues within CE. The first time through the cycle, design is not mature (e.g., 10% mature). The key to design maturity is that the multi-disciplinary design team goes through iterative cycles of the CE continuum/concurrency loop until 100% design maturity is achieved (U. Menon, personal communication, October 1996). The goals of the design maturity curve are for a design team to make changes and to address potential manufacturing problems early in the design process to reduce the number of design specification change orders. The ultimate goal is to have error-free assembly once the product goes into production (Menon, 1992b).

Concurrent Engineering Design Plan

The CE approach promotes the allocation of extra design time to create a successful product. The increase of design time ensures error-free manufacturing, the reduction of rework, and the timely release of a product to market (Turino, 1992). A company can lose significant revenue by product market delay. It is estimated that if a product were released one month late, 12% revenue would be lost. Lost revenue increases to 54% with a five-month delay (Carter & Stilwell-Baker, 1992). The increase in design time results in an overall reduction of time because rework and delays in manufacturing are reduced (Turino, 1992).

Companies are challenged by continually changing markets. They construct products correctly and still do not have a viable market. A CE goal is for a design team to make correct design decisions by meeting consumer needs and wants. Consumer needs and wants must be understood clearly by the design team. Products designed by using CE focus on customer wants, needs, and expectations. To capture consumer needs, a design

team conducts market research, observes competitors, looks at previously designed products, and uses archival knowledge. To ensure product competitiveness, the CE team talks to consumers and customers, stays in continual contact with customers, and monitors continually changing consumer preferences (Carter & Stilwell-Baker, 1992). End-use consumer and customer requirements are stated as design inputs and outlined in a design plan. To achieve customer satisfaction, the CE design plan has four stages: plan, perform, study, and act (Ehresman, Reid, & Wayne, 1991).

The first stage in the CE design process is plan creation. The plan stage includes developing (a) a scope and direction for design activities, (b) a list of resource needs, (c) an action plan, (d) an understanding of consumers and their requirements, (e) a method to evaluate competitor products, (f) design alternatives, and (g) test and evaluation plans (Ehresman et al., 1991).

The second stage in the CE design plan is design creation or the perform stage. During this stage, the activities performed are to translate consumer and customer expectations into product requirements, to create a product definition that includes drawings and specifications, and to create product prototypes (Ehresman et al., 1991).

The third stage outlined in the CE design plan is the study stage. During the study stage, the design team evaluates projected outputs against customer expectations. Design deficiencies that do not meet customer expectations are identified and the product is changed. Specific activities during the study stage are to perform design reviews and product tests and evaluations.

The fourth stage is action, which refers to the identification of changes and design improvements. The activities during the action stage are to evaluate activities from the study stage, to resolve design problems, and to make design improvements. By using a design plan, CE formalizes design outputs that include product definition information,

prototypes, consumer market information (e.g., projected sales), and financial information (e.g., profit requirements) (Ehresman et al., 1991).

Concurrent Engineering Analytical Design Process Models

Many analytic graphic model variations of the CE process are described in the literature. The CE analytic graphic models have commonalities; however, CE has been criticized because there is not a widely accepted framework for CE implementation (Schmitz & Desa, 1992). The following CE models are reviewed in this section: Crow's (1992) CE framework, Schmitz and Desa's (1992) Virtual CE model, Sharon's (1992) Closed-loop CE process, and Turino's (1992) CE parallel processes model.

Crow's (1992) framework represents an overall CE process that shows the interaction between the design requirements (e.g., manufacturability, cost) with the use of automation, enabling technology, and the implementation of multi-disciplinary teams (see Figure 6). Crow's framework promotes a multi-disciplinary team in which suppliers are involved with product design requirements. The enabling technology represents ways that the CE process can be streamlined and organized.

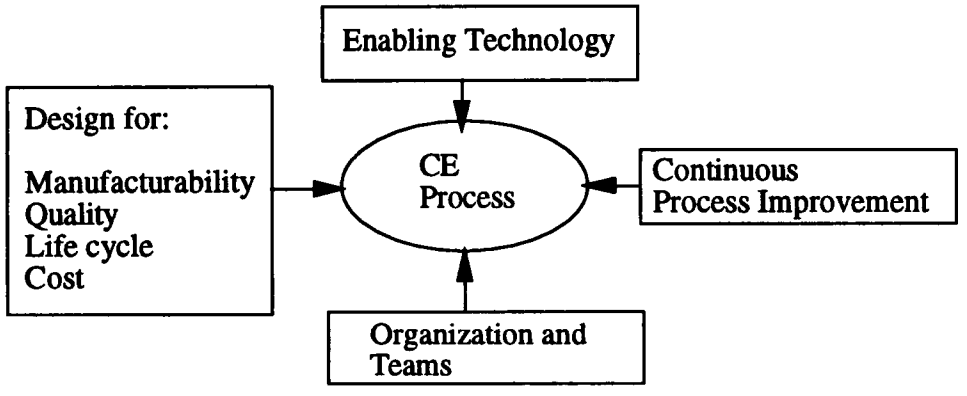


Figure 6. Concurrent Engineering framework (adapted from Crow, 1992, p. 2-3).

Schmitz and Desa (1992) developed a virtual CE model (see Figure 7) that combines product development goals with a CE computer-based environment. This information is needed to optimally balance product design with product parameters (e.g., cost, assembly, reliability). In the model, dashed lines indicate steps that can be computerized. Schmitz and Desa (1992) note that successful CE implementation relies on the use of computer tools. Automated and computerized design tools help CE design teams. One effective design tool includes component libraries. Component libraries are intended to contain product specifications and operational characteristics used in a design. Schmitz and Desa's model supports the ideal design process as defined by Carter and Stilwell-Baker (1992). They recommend using previously designed and tested components rather than creating a product from scratch every time.

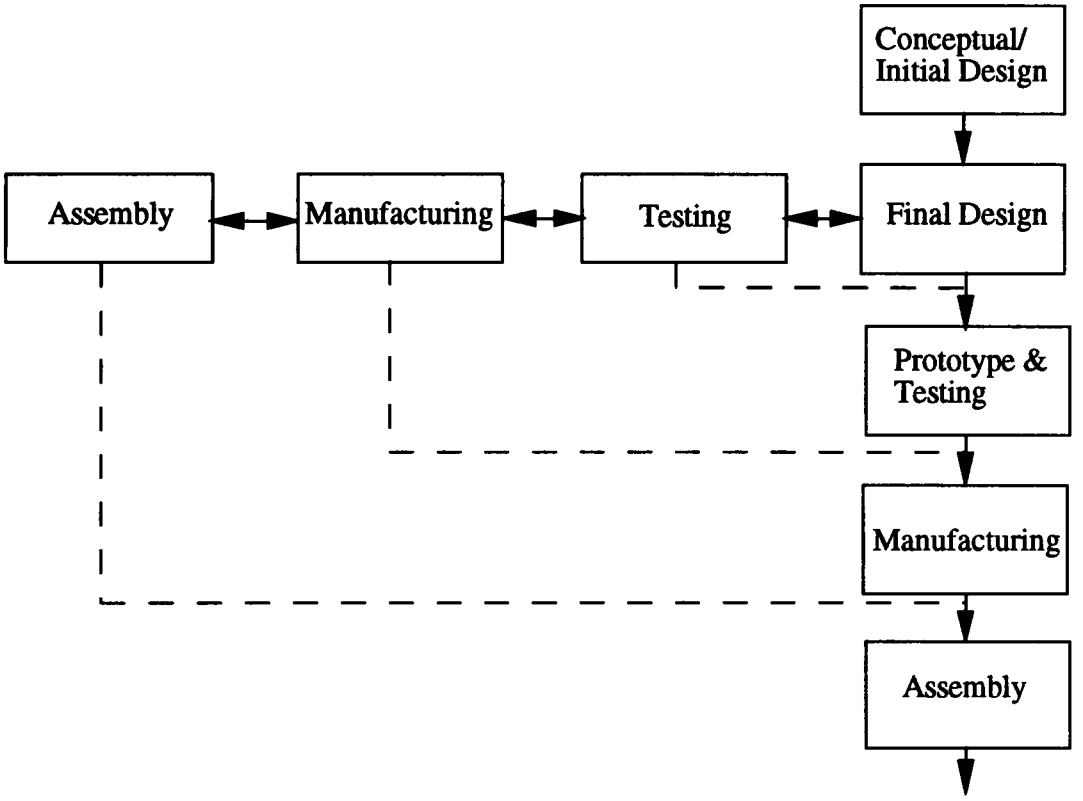


Figure 7. Virtual Concurrent Engineering (adapted from Schmitz & Desa, 1992, p. 358).

Sharon's (1992) CE model in Figure 8 illustrates that design concepts and manufacturing processes are addressed simultaneously. Solutions generated are developed and implemented in parallel. Sharon's model shows that, in order for CE to have more control, it should be thought of as a closed-loop process. Primary bottlenecks of CE that were addressed in this model included problems with early decision making capability, feedback technologies, and people. The feedback loops drawn in Sharon's model indicate where product design could be optimized through the design team's continual evaluating and decision making. The information presented in Sharon's model is supported by Carter and Stilwell-Baker (1992). Carter and Stilwell-Baker indicate that the design team needs documentation that pinpoints product and development process improvement so that they can evaluate and make decisions which will improve the next design iteration (Carter & Stilwell-Baker, 1992).

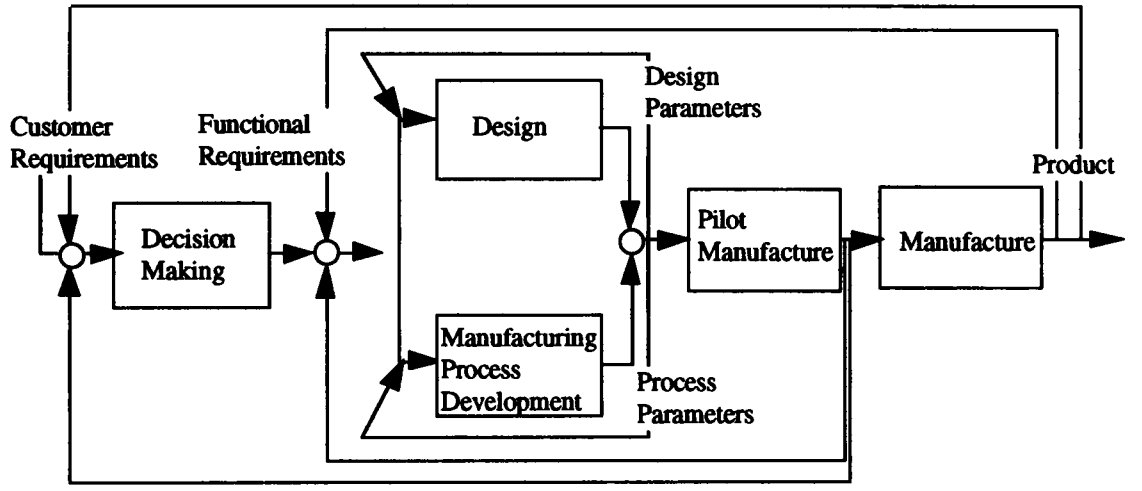


Figure 8. Closed loop Concurrent Engineering process (adapted from Sharon, 1992, p. 7).

Turino's (1992) CE process model promotes the concept that design process attributes (e.g., performance, manufacturability) are treated as equal to and parallel with product design attributes (e.g., cost, quality). A key attribute of Turino's model is the

integration of engineering expertise early and simultaneously during the design phase (see Figure 9).

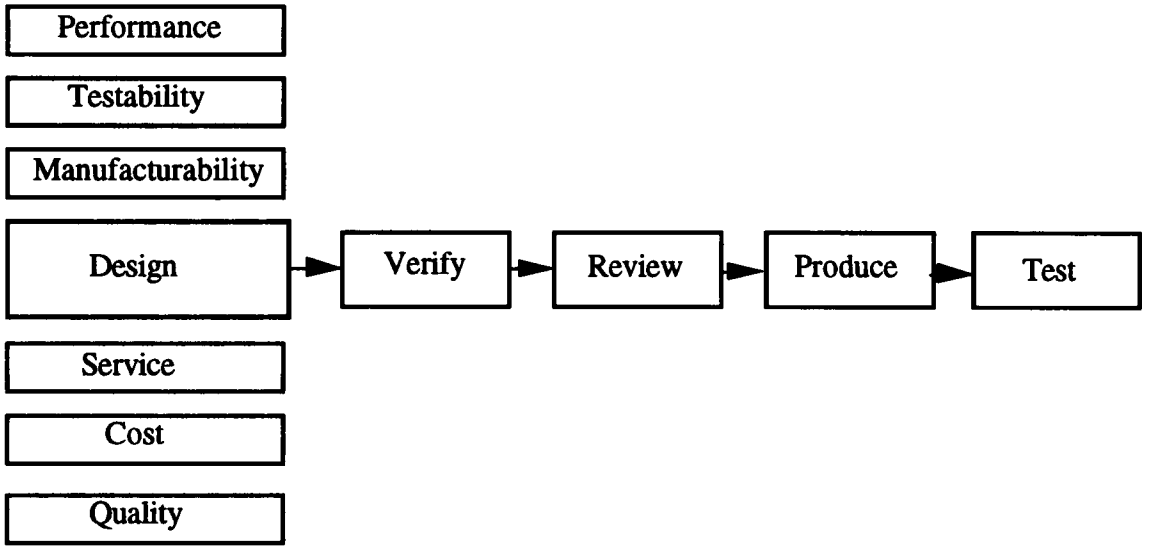


Figure 9. Concurrent engineering parallel processes (adapted from Turino, 1992, p. 2).

Common among all of these models is the integration of product development decisions into the conceptual design phase. In the CE analytic graphic models, the design team makes decisions early in the design process about quality, use of equipment, costs, and other production-related decisions. These CE models contrast with the sequential manufacturing process by showing that critical product development decisions are moved from late in the process to early in the process. When combined with the design maturity curve concept, these CE models show that the multi-disciplinary team can make early decisions at a low-cost stage and at a point when design revisions require limited rework. These CE models also show the use of computer information structures (e.g., process planning, automation, costing simulation) to improve the design and product development process.

Concurrent Engineering Design Conceptual Statements

Crow's (1992), Sharon's (1992), and Turino's (1992) CE models show that decision making is important during the design phase. The terms used for design team decision making in CE models and CE literature are inconsistent. Some common phrases used in literature are design for X, functional requirements, design constraints, or design parameters. Henceforth, the present study will use CE conceptual statement as a generic phrase to represent specific decisions made by the design team. The design teams use the CE conceptual statement areas as constraints to ensure that design and processes are considered and influence each other in a timely and effective way before, rather than after, production has started (Vujosevic & Kusiak, 1991; Wheelwright & Clark, 1992). A conceptual CE model adapted from Crow (1992) and Hyeon et al. (1993) represents the CE conceptual statements (see Figure 10). In CE literature, the CE conceptual statement areas are described as design for manufacturability (DFM), quality (DFQ), cost (DFC), life cycle-inspectability (DFLC-I), life cycle-reliability (DFLC-R), life cycle-maintainability (DFLC-M), and enabling technology (DFET) (Carver & Bloom, 1991; Crow, 1992; Hyeon et al., 1993; Maddux & Souder, 1993; Sharon, 1992; Shina, 1991; Turino, 1992).

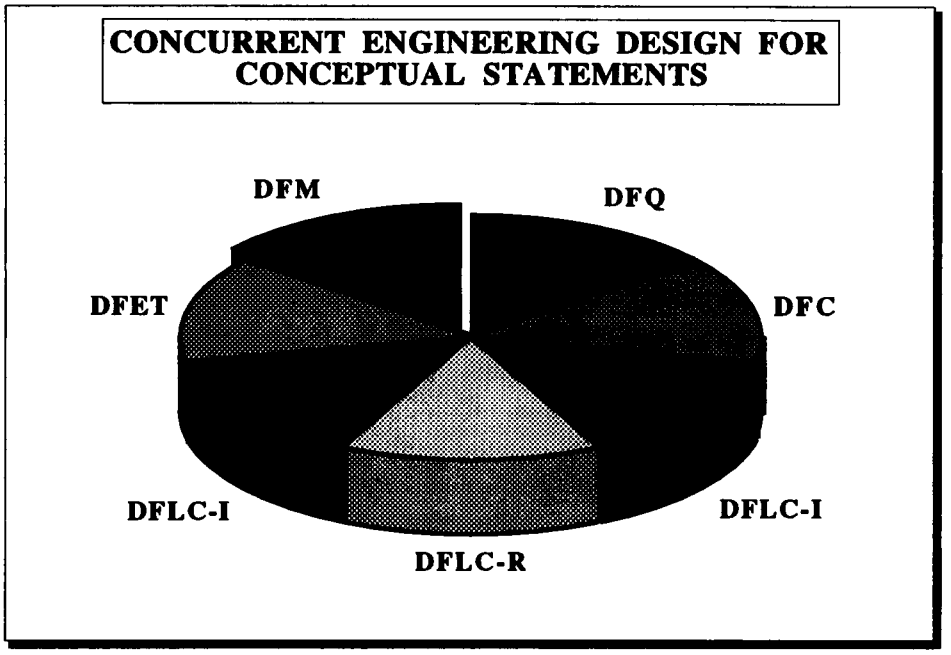


Figure 10. Concurrent engineering conceptual statements (adapted from: Crow, 1992; Hyeon et al., 1993).

Design for Manufacturability (DFM)

DFM is defined as designing producibility into a product rather than modifying a design to correct deficiencies prior to manufacture release (Crow, 1992). Bralla (1996) indicated that Geoffrey Boothroyd and Peter Dewhurst have been instrumental in the development of DFM. A review of literature delineated DFM operational statements as (a) considering manufacturability at the start; (b) designing producibility into the product; (c) designing for ease of assembly by minimizing flexible parts, interconnections, and number of product components; (d) designing for ease of fabrication by using standardized materials; (e) minimizing design variation by using standardized parts to promote mistake-proof design; (f) orientating parts for minimization of nonvalue-added activities; (g) using modular components to have efficient joining and fastening; (h) requiring ergonomics and human factors; (i) encouraging group technology; (j) inspecting or measuring at the source; (k) having minimal handling to reduce matching or job set-up

time; and (l) promoting management systems and team organization (Carver & Bloom, 1991; Crow, 1992; Hyeon et al., 1993; Maddux & Souder, 1993; Sharon, 1992; Shina, 1991; Turino, 1992). A DFM construct that has received extensive study is design for ease of assembly. Literature outlined design for ease of assembly as an approach to designing product for part number simplification, standardized part use, modular component use, and component part library use (Crow, 1992).

The overriding goal of DFM is to evaluate and improve manufacturability and assembly during the design process (Boothroyd, 1992). Crow (1992) detailed DFM goals as improving design by having the design team evaluate designs for cost-effectiveness, production process feasibility, cycle time reduction, manufacture improvement, and specialized production requirements. To meet goals, DFM has specific objectives for design team implementation. The specific DFM objectives are for the design team to: (a) understand the company's customer, (b) involve suppliers and subcontractors early, (c) use quality engineering and reliability techniques, (d) create an efficient development approach, and (e) integrate computer-aided design with computer-aided manufacturing. Integrating design with manufacturing can be accomplished by using 3-D computer product models, standard computer languages, and computer simulation of product performance and manufacturing processes.

To ensure DFM success, quantifiable metrics need to be used by the design team (Hyeon et al., 1993). DFM is measured by evaluating a product design for cost estimation, time estimation, and process visualization. Manufacturing cost estimates are calculated by the addition of costs for material, equipment, labor, tooling, and overhead. Time estimates are determined by calculating the time needed for specific manufacturing operations. Process visualization is determined by the designer envisioning a manufacturing process and identifying processes that potentially decrease efficiency (Shankar & Jansson, 1993).

Design for Quality (DFQ)

Ehresman et al. (1991) defined DFQ as designing a product that conforms to customer requirements. By using DFQ, the design team starts by designing products for customer requirements. Evaluating customer requirements provides information to the design team for selection of high quality components, design of products with an attractive look and feel, and a benchmark of how their product compares with competing products. To meet customer requirements, the design team uses the following DFQ operational statements: (a) Quality Function Deployment/House of Quality, (b) Taguchi quality engineering, (c) functionality built into the product, (d) average part quality level maximized, and (e) the number of parts minimized. By using Taguchi quality engineering methods, the design team improves product reliability through setting specific values for design parameters, establishing acceptable tolerances, and developing a robust product to counter or minimize potential manufacture variation (Carver & Bloom, 1991; Crow, 1992; Hyeon et al., 1993; Maddux & Souder, 1993; Sharon, 1992; Shina, 1991; Turino, 1992).

Consideration of end-users is an important factor in a product's potential success (Blaich & Blaich, 1993). The primary DFQ goal is that the voice of the customer drives product design. To meet this goal, DFQ ensures that a design team creates a product that meets or exceeds customer expectations, minimizes manufacture variation, improves product reliability, and meets performance and technology standards (Crow, 1992). DFQ objectives are to design a product that meets consumer requirements, consumer desires, and consumer preference. Information concerning consumer requirements, needs, and preferences is obtained through customer contact, surveys, customer specifications, observations of use, field testing, and sales data (Ehresman et al., 1991). Staying in touch with the consumer is most critical to successful design and product development (Blaich

& Blaich, 1993). Using DFQ, the design team continually assess consumer and customer requirements to determine whether they are being met (Carter & Stilwell-Baker, 1992).

One method used to measure design quality is Quality Function Deployment (QFD) (Ehresman et al., 1991). QFD is a planning tool that incorporates product attributes with customer expectations (Menon, O'Grady, Gu, & Young, 1994). Using QFD, the design team draws a relationship matrix to document and analyze consumer and production requirement relationships. QFD creates a proactive rather than reactive approach to solving design problems (Ehresman et al., 1991). The steps to QFD are (a) study and listen to consumers to determine superior product needs and preferences, (b) break down product needs and preferences into customer attributes, (c) weigh customer attributes based on relative importance to the customer, (d) develop a QFD matrix to make engineering, marketing, and design decisions, and (e) compare and rate a company's product with those offered by competitors (Chase & Aquilano, 1992).

A QFD matrix, commonly called *the house of quality*, is used to form a conceptual map of customer attributes that translates consumer requirements (i.e., the whats) into product engineering specifications (i.e., the hows) (Carter & Stilwell-Baker, 1992). Figure 11 shows a QFD matrix. The matrix creates relationships that tie consumer requirements, *the whats*, with specific design requirements, the *hows*. A correlation rating of strong, medium, or weak relates the consumer *whats* with engineering *hows* (Chase & Aquilano, 1992). QFD is decomposed into more detailed QFD to further break down product attributes and requirements (Carter & Stilwell-Baker, 1992).

The AAMA (1994) states that apparel manufacturers should be aware of customer preferences about value, flexibility, service, quality, and innovation. QFD is a useful tool in identifying customer preferences. For QFD success, designers must have an accurate voice of the customer (Menon et al., 1994).

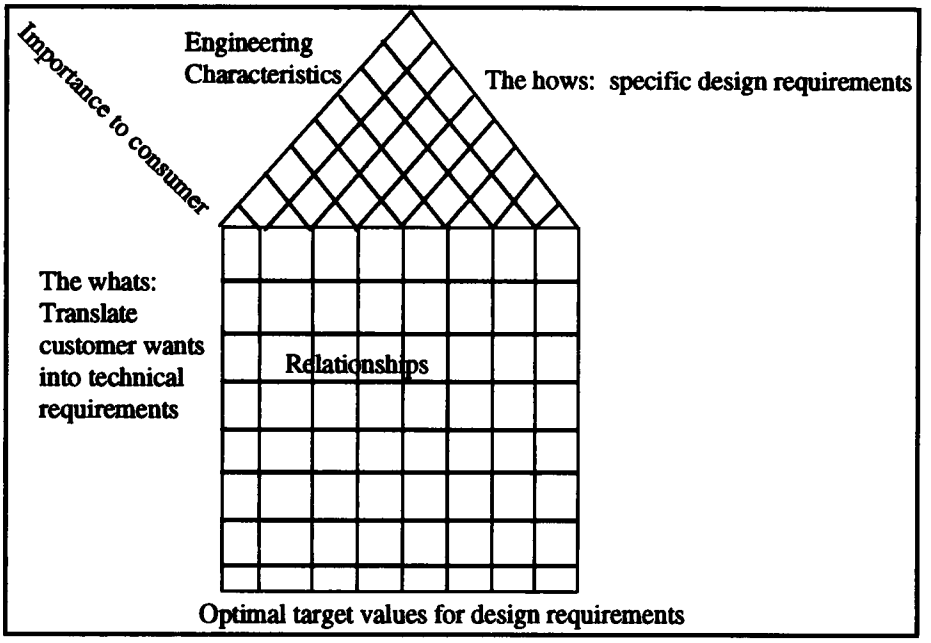


Figure 11. QFD Matrix (adapted from Chase & Aquilano, 1992; Ehresman et al., 1991).

Design for Cost (DFC)

Design for Cost is defined as designing a product to a set target cost (Crow, 1992). For example, a target cost of $20.00 for a shirt would act as a design constraint rather than as a cost evaluation factor after the product was designed. A review of CE literature delineated DFC operational statements as: (a) creating target costs for products, (b) designing for assembly cost method, (c) utilizing life cycle costing, and (d) using a tracking system that monitors cost targets. A DFC goal is to reduce costs through reducing delays in time-to-market (Carver & Bloom, 1991; Crow, 1992; Hyeon et al., 1993; Maddux & Souder, 1993; Sharon, 1992; Shina, 1991; Turino, 1992).

Problems occur when design activities operate in isolation of pricing decisions. The majority of decisions affecting price take place during design and product development before the product design is released to production. Many designers have limited knowledge of manufacturing; therefore, their design decisions can increase production costs. By the end of the design stage, 65% to 95% of a product cost is fixed

(Syan, 1994). The consequences of design decisions that increase production costs are referred to as excess cost or hidden cost (Blanchard et al., 1995; Duffey & Rosen, 1994).

Measuring cost in a CE environment is impeded by traditional cost accounting procedures because traditional cost accounting does not capture hidden costs (Blanchard and Fabrycky, 1990; Carter and Stilwell-Baker, 1992; Turino, 1992). A company must carefully document costs for an accurate cost measure. Calculating an individual department's costs by direct labor cost and operational costs (e.g., overhead) reveals only part of the financial picture. The costs of rework, machine retooling, and time delays are hidden costs. Traditional cost accounting does not identify important benefits such as better quality, faster time-to-market, quicker order processing, and higher customer satisfaction (AAMA, 1994; Carter and Stilwell-Baker, 1992). Using DFC methods can help the design team to predict price and product profitability. The design team tracks a product's profitability from design through manufacture, test, and service. The advantage of tracking profitability is that it creates a holistic picture of total costs rather than separate functional costs (Turino, 1992).

Designers need access to costs during the design phase to design to a set cost goal. One DFC tool is a historical cost database which includes information on estimated costs for previous designs, raw materials, assembly times, machining, and testing for different designs and different production situations (Boothroyd, 1992; Hyeon et al., 1993). One type of DFC historical database used during the design process is called quick cost estimation. Quick cost is defined as a simplification of actual costs that are available during the design stage (Hundal, 1993). Some apparel manufacturers use quick cost programs during product development. Apparel quick cost programs estimate direct product cost based on historical apparel styles stored in a database. This method allows for quicker style cost estimates to retail buyers (L. Young, personal communication, August 1994).

DFC tools that calculate comprehensive product and process costs are used later in the product development stage. The DFC tools include accounting for cost for design, raw materials, trade-off decisions, assembly, rework, testing, customer service costs, and time-to-market delays (Turino, 1992). The common comprehensive DFC cost calculation methods outlined in the literature were (a) the Boothroyd and Dewhurst design for assembly costing method, (b) activity-based costing, and (c) product life cycle costing (Boothroyd, 1992; Duffey & Rosen, 1994). Developed during the 1980s, Boothroyd and Dewhurst's design for assembly costing is a method used to calculate product attributes affecting assembly cost and production cycle time. The design for assembly approach includes a calculation for total cost of machine operation. The total machine cost includes operator wages, overhead changes, machine operation costs, machine depreciation, irregular cost, and average production time (Boothroyd, 1992). Activity-based costing allocates overhead cost values to appropriate support activities (e.g., training, quality control) to product total cost. A proportional dollar value is assigned to the products that have used a support activity (AAMA, 1994). Product life cycle cost methods include inventory costs, product service and maintenance costs, environmental costs, production set-up cost, and development cost (Duffey & Rosen, 1994).

Design for Life Cycle-Inspectability (DFLC-I)

As indicated in the CE definition, the CE approach is for the multi-disciplinary design team to evaluate product designs for life cycle issues. The scope of a product life cycle is from design conception through product disposal. In order for the multi-disciplinary design team to evaluate product life cycle, they look at issues on disposing, inspecting, implementing safety, installing, maintaining, manufacturing, producing for reliability, testing, and upgrading a product (Crow, 1992; Menon, 1992a). A review of CE literature delineates the common product life cycle conceptual statement areas as

inspectability, reliability, and maintainability (Carver & Bloom, 1991; Crow, 1992; Hyeon et al., 1993; Maddux & Souder, 1993; Sharon, 1992; Shina, 1991; Turino, 1992).

DFLC-I is defined as the ability to make design choices that will minimize product development cost by having needed equipment to test or inspect a product at various production stages. DFLC-I operational statements are: (a) early involvement of quality assurance; (b) geometric dimensioning, tolerancing, and standard connections; (c) specification of product parameters; (d) automated equipment compatibility; and (e) built-in test diagnostic capability and standard instruments (Crow, 1992). The overriding goal of DFLC-I is for the design team to build quality into a product rather than inspecting quality out of a product. To achieve the DFLC-I goal, the design team needs to involve QA with design decisions. By involving QA, the design team can make product design decisions that are compatible with inspection processes, product tests, and test equipment costs. QA can then set up standard test procedures that are not too expensive for the volume of production. As a starting point, the design team can use benchmarking as a tool to determine criteria for inspectability. Benchmarking involves comparing a company's products, services, and practices with those of competing companies (Crow).

Design for Life Cycle-Reliability (DFLC-R)

DFLC-R refers to evaluating a product's ability to remain functional for a specified period of time when used for its designated purpose (Blanchard et al., 1995). To accomplish DFLC-R, the multi-disciplinary design team needs to involve reliability engineers and encourage the use of vendor-partner relationships in the design process. DFLC-R operational statements include (a) perfecting a prototype through design and test iterations, (b) testing designs with computer-aided engineering tools, (c) applying Taguchi quality engineering, and (d) using proven standard parts (Crow, 1992). The goal for DFLC-R is to determine the most cost-effective approach by eliminating defects and early failures prior to shipping the manufactured product (Birolini, 1993). For effective

DFLC-R, the design team needs to consider reliability issues early in the design process (Crow, 1992).

The design team predicts DFLC-R by using reliability analyses. One common reliability analysis is mean time to failure prediction. A mean time to failure prediction is useful for the design team to detect product weaknesses, to determine reliability improvements, and to compare alternative solutions (Birolini, 1993; Blanchard & Fabrycky, 1990). Tools used to analyze DFLC-R include computer simulation tools, reliability prediction models, and QFD. Using QFD, the design team can compare documentation of consumer requirements with product reliability and production requirements (Womack, Jones, & Roos, 1990).

In apparel and textile manufacture, reliability is commonly associated with quality assurance tests performed on raw materials and on finished products. A reliability rating for a fabric is determined by performing multiple textile sample tests to determine how a fabric will perform under specified conditions. Product reliability is attained if multiple product samples have the same results, or if the test results of product samples for like products, tested in different laboratories, have the same results (Merkel, 1991).

Design for Life Cycle-Maintainability (DFLC-M)

Blanchard et al. (1995) defined DFLC-M as the consideration of the actions necessary to retain or restore a product to a desired condition. Maintainability operational statements include (a) products designed for maintenance and repair; (b) trade-off consideration on product use, cost, and reliability; (c) modular design replacement; and (d) available and inexpensive part use. The goal of DFLC-M is to evaluate a product in terms of parts or components that are subject to wear. Maintainability importance can differ for consumable products and nonconsumable products, product reliability rating, and product cost (Crow, 1992).

Merkel (1991) describes maintainability as textile and garment serviceability. Apparel product maintainability (i.e., serviceability) depends on the expected life cycle of a product. A man's tailored suit may have an expected life cycle of ten years; however, a trendy mini skirt may have an expected life cycle of one season. Apparel and textile manufacturers evaluate maintainability through testing garment or fabric wear, seam strength, garment stress points, and fabric performance (Merkel). Maintainability is measured by calculating the probability of a failed item replacement within a specified amount of time with specified resources (Bilatos & Basaly, 1994). DFLC-M tests must be completed early in the development process to provide appropriate information to the design team (Hyeon et al., 1993).

Design for Enabling Technology (DFET)

DFET is defined as concurrent sharing of information in a seamless, cooperative environment (Prasad, 1996). Users of DFET share design process information by means of data interchange through digital process models. The interchange of design process data through digital product models maintains a consistent and up-to-date design representation for the manufacturing process (Chen, 1994). Thus, if one team member changes data in a computer system, the change occurs in all other systems and tools used (e.g., databases, computer-aided design [CAD] programs) (Carter & Stilwell-Baker, 1992).

A review of CE literature delineated DFET operational statements into three categories: design process information, data interchange, and digital product models. DFET operational statements for design process information are to (a) specify production equipment layout and manufacturing process plans that are compatible with product needs, (b) program parts and assembly, and (c) design tools and fixtures. The DFET data interchange operational statements include extending digital product data externally, interchanging electronic data, and exchanging product data using the standard for the

exchange of product model data (STEP). The DFET operational statements for digital product models are (a) optimizing design information (digital model) by using CAD solid modeling; (b) accumulating repeatable design knowledge by storing information in a logical, consistent, nonredundant, and reusable manner; (c) avoiding paper drawings by using 2-D or 3-D CAD systems; and (d) using CAD feature-based representation (Carver & Bloom, 1991; Crow, 1992; Hyeon et al., 1993; Maddux & Souder, 1993; Sharon, 1992; Shina, 1991; Turino, 1992). The goal of DFET is that the design team will share knowledge (Carver & Bloom). To meet the DFET goal, CAD systems need to be integrated with computer-aided manufacturing (CAM) production systems. By having CAD/CAM integration, tools and machine type information act as a design constraint to aid the CE design team's knowledge of a product's manufacturing process (Crow).

Successful implementation of DFET data interchange requires the use of standard neutral computer languages to transfer digital information through the use of computer equipment. Problems can occur when CAD systems operate in computer languages that differ from CAM production systems (Moncarz, 1992). Moncarz reported that apparel CAD/CAM systems need better integration. The lack of CAD/CAM system integration can lead to mishandled information, errors in the information handled, lost items, and product design re-creation multiple times in separate departments (Crow, 1992). The U.S. National Institute of Standards Technology (NIST) promotes the use of a standard computer graphic language (e.g., apparel product data interchange system [APDES]) that is not dependent on computer type or brand. For example, the use of APDES allows the exchange of design information from a basic pattern created in a CAD program to be transferred to an automatic cutter.

The use of DFET tools allows the virtual team members to easily exchange and share information through computers. DFET tools include shared workstations and shared software programs. The virtual (i.e., co-located) team can use shared workstations,

a local area network, or a wide area network to have concurrent access to engineering data and applications (Chen, 1994). Common shared systems are a multi-window approach where multiple members of the design team can access product information and can work on a project at the same time (Carver & Bloom, 1991). Computer software programs assist in the concurrent design process and the communication of information between machines (Menon, 1992a). DFET software programs are designed to share design information. Some software programs for design include CAD imaging systems, enterprise data access, design communication, product data exchange, and process data exchange (Prasad, 1996).

The design team gives equal consideration to each of the CE conceptual statement areas of DFM, DFQ, DFC, DFLC-I, DFLC-R, DFLC-M, and DFET (see Figure 10). As Crow's (1992) CE framework illustrates, the CE conceptual statement areas are a part of the total CE approach. As Crow's CE framework model illustrates, the complete CE approach requires organizational change and team use (see Figure 6).

Concurrent Engineering Organizational Issues

Successful CE requires a new attitude to conduct product development. CE implementation has specific requirements for management, the organization, equipment, technology, and human resources. An organization that implements CE needs a foundation to enlist management support, develop teams, and use appropriate equipment (Mills, et al., 1992). Carter and Stilwell-Baker (1992) stress the importance that management evaluates needs for new tools and processes according to CE needs, rather than according to old process needs.

Concurrent Engineering Management Requirements

Top management needs to understand and embrace CE to ensure the success of this approach (Maddux & Souder, 1993). CE effectiveness is dependent on management's provision of an environment that allows for the exchange of information.

Successful CE implementation requires upper management support, a company culture that accepts change, employees who are willing to change the organization, and a sense of product ownership among employees toward product development (Maddux & Souder; Mills et al., 1992). For successful implementation and sustainability of any new CE program, this management support is essential (Salomone, 1995). CE implementation requires management to characterize the current business strategy, operations, and systems; to create a product development vision; to implement the vision through change management; and to continually improve the CE vision and CE process (Spears, 1992). New programs and organizational structures are needed, including (a) CE educational programs, (b) quality management methods, (c) design policies that enable change, and (d) supplier involvement in the design process (Maddux & Souder).

Concurrent Engineering Organizational Requirements

CE requires organizational culture change, because it is a nontraditional approach to the design process (Maddux & Souder, 1993). In a CE environment, old product development practices are uprooted. The process is no longer sequential. Instead of an *over the wall* approach, a multi-disciplinary team communicates across organizational boundaries (Syan, 1994). CE has specific organizational requirements which are to develop teams, enabling technologies, and budgets that are compatible with a CE environment (Salomone, 1995). To implement CE, managers need to (a) encourage cooperation among functional staff areas, (b) establish reward systems based on organizational-wide objectives, (c) promote good communication among the company, customers, and suppliers, and (d) create a positive environment for the exchange of information. Managers must allow sufficient time for organizational change and generation of benefits for CE success (Maddux & Souder).

Concurrent Engineering Equipment and Technology Requirements

The CE approach is dependent on people having the capability to work on a project, to simultaneously communicate with each other, to use the same set of specifications, and to use compatible equipment (Maddux & Souder, 1993). Interpretations of CE technical requirements vary. Wheeler (1991) indicates that the only tools and technology needed are paper, a pencil, and the ability for people to work with others. On the other hand, Schmitz and Desa (1992) indicate that CE implementation is not feasible without computers.

Management needs a thorough understanding of CE to expend the appropriate capital outlay for equipment. Maddux and Souder (1993) warn that simply buying CAD/CAM equipment does not ensure CE success. Technical computer requirements include CAD/CAM equipment and available process manufacturing information (e.g., minimum material requirements) during the design process (Jones, 1973; Maddux & Souder). Computer automation can help companies effectively manage complex tasks by allowing numerous people to work on a project at the same time (Carter & Stilwell-Baker, 1992).

Repeated design success depends on the CE multi-disciplinary team having access to design research information. Computer networks, knowledge-based expert systems, or CAD systems help designers by providing access to design information (Committee on Engineering, 1991). Successful product design also requires the team to have knowledge of extensive technical specifications, product requirements, manufacturing processes, design processes, and recollection of the success or failure of previous projects. Often a problem occurs when design knowledge for individuals is heuristic and is not easily accessible to other company individuals (Committee on Engineering, 1991). The multi-disciplinary team benefits when design information is stored in archives to include product use, sell-through, comparison to competing products, compatibility with the

company's current product range, and product ease-of-use (Blaich & Blaich, 1993). Computer knowledge-based systems that are accessible to the design team and other company associates are powerful design and business tools (Committee on Engineering, 1991). The CE multi-disciplinary team continually needs to address the concurrent development of product designing with manufacturing processes. To address concurrent development, team members must have an understanding of internal and external product requirements, trade-off issues, design alternatives, and how to secure consensus on the design and production of a product (Crow, 1992; Maddux & Souder, 1993).

Concurrent Engineering Human Resources Requirements

Implementing the CE approach requires change in human resources practices (Pawar, 1994). CE has human resources requirements that include the use of multi-discipline teams, virtual teams, quality management, and continuous improvement commitment (Menon, 1992b). CE requires teamwork and team consensus for design solutions. Managers need to encourage and financially reward people to work in teams rather than for specializing and working individually (Crow, 1992; Labich, 1994; Sharon, 1992). Team cohesiveness requires education programs (Blaich & Blaich, 1993). Management needs to provide continuing education for the multi-disciplinary team on new tools, new design techniques, reference literature breadth, current research relevant to industry practices, and communication between internal team members and external suppliers (Committee on Engineering, 1991).

The Concurrent Engineering Design Team

In contrast to the design of a product being one individual's responsibility, CE uses a product development team to solve the design problem (Pawar, 1994). A company's success with CE is dependent on the effectiveness of the multi-disciplinary team (Maddux & Souder, 1993; Rosenblatt & Watson, 1991). The CE approach requires

the multi-disciplinary team to have functional department representation, team leadership, budget guidelines, and schedule controls (Maddux & Souder).

People assigned to product development teams often have different personalities and perspectives (Crow, 1992). Both the right and left brain hemispheres use high-level cognitive modes that involve reasoning, thinking, and complex mental functioning; however, individuals have one brain hemisphere that dominates the other. Creative people, such as apparel designers, tend to be trained in art and design concepts, and exhibit a dominance toward lateral thinking (e.g., right-brain skills). An individual's right-brain hemisphere is nonverbal, holistic, concrete, metaphoric, irrational, spatial, intuitive, insightful, and relational (Edwards, 1979). Apparel and textile technology individuals are analytic, sequential, and linear thinkers (e.g., left-brain skills) (Knox, 1989). Individuals with left-brain dominance generally are noted as verbal, analytic, symbolic, abstract, time conscientious, rational, sequential, digital, logical, and linear. Left-brain dominant individuals perceive in ways that interfere with drawing, and creative right-brain individuals transform ordinary data into new creations and process information on spatial problems (Edwards).

Recognition is needed for the differences between creative (e.g., right brain) and logical (e.g., left brain) individuals who work on teams (Knox, 1989). A person with right-brain dominance generally is not good at sequencing and tends to start a project anywhere. A person with left-brain dominance, however, thinks sequentially and prefers to start at the beginning of a project (Edwards, 1979). Individuals who are creative thinkers are needed to innovate products or processes and major companies are starting to recognize them. For example, executives for Hallmark Cards, Inc., participated in a creative leadership course to promote an understanding of creativity by developing and executing a line of cards (Farnham, 1994). Having both left-brain and right-brain dominant individuals on a multi-disciplinary team is beneficial. Creative individuals

contribute to improved product design, creativity, and innovation (Maddux & Souder, 1993). Having a variety of individuals allows for varying perspectives on the product being designed. The interaction of individuals from differing disciplines has a positive effect on employee interaction (Carter & Stilwell-Baker, 1992). Important benefits of having a variety of individuals work together are increased sharing of knowledge throughout an organization, people addressing complex design issues, and employees understanding the business (Pawar, 1994).

Designers. The designer's role is extremely valuable and pivotal to a company's success. "Designers are very important to a company as they often make million dollar decisions without ever knowing it" (qtd. in Hyeon et al., 1993) p. 1). In CE, design becomes integrated into the organization, requires a balance in designer management, and increases a designer's power. If a designer has too much power, the organization becomes unbalanced, and the designer is blamed for causing costly problems. With proper designer management, many product development problems can be detected early and corrected (Carter & Stilwell-Baker, 1992). To keep the organization in balance, managers need to have an understanding of how to manage designers. Farnham (1994) indicated that designers are often poorly managed. Design managers with successful design management programs understand that designers should not be punished for design failure, need deadlines, have recognition for design achievement, and need some direction. Successful design managers know that people, not creativity, are managed and a designer's sense of autonomy should not be ignored (Committee on Engineering, 1991; Farnham, 1994). To ensure that designers do not lose sight of customer needs, management must require designers to be accountable for creating a producible product that is a good solution to providing for consumer needs. CE designers must balance consumer needs with creative impulses (Maddux & Souder, 1993). As emphasized in CE, Leech (1972) indicates designers need to consider cost, operation, manufacture,

economic implications, and intended design environment when designing a product (Leech, 1972).

A designer's primary objective is to satisfy a customer; however, he/she is sometimes criticized for designing the wrong solution in terms of time, money, or chance. This situation frustrates some designers, because they expect to be judged on ingenious design rather than for commercially workable designs (Leech, 1972).

Designers are stereotypically thought of as cute, eccentric, temperamental, and high maintenance (Committee on Engineering, 1991). While some designers do not want to conform to company formalities, they tend to be (a) obsessively dedicated to their work, (b) self-motivated, and (c) risk-takers (Farnham, 1994). Effective designers generally have eclectic interests, draw parallels from other fields for ideas, and respond to design problems with many ideas rather than with one solution. Designers have strong, inner-directed personalities in which they are appreciative of novel ideas and not afraid of ambiguity (Committee on Engineering, 1991). The stimulus for creativity varies among designers. Some needs for creative people include (a) a preference for silence, (b) a stimulus from travel, (c) a need for non-conforming creative offices, (d) interaction with other people, and (e) autonomy (Farnham, 1994).

Multi-discipline team members. Managers assign people from functional departments who are important to the development of a product (Crow, 1992). Multi-disciplinary CE teams include people from design, manufacture, market research, finance, and service departments (Pawar, 1994). The individuals work together concurrently to consider costs, quality, schedules, and user requirements (Yannoulakis et al., 1991). Multi-disciplinary teams strive to create a designed product that is producible and usable. To create the designed product, the teams collaborate and agree on product designs evaluation for design requirements, product function, production method efficiency, assembly sequencing, and quality consistency (Whitney, 1988). Effective

multi-discipline teams have self-direction, the power to make decisions, and product ownership (Sharon, 1992).

Physically locating multi-disciplinary design teams in the same office space can improve design and manufacturing (Pawar, 1994); however, sometimes having the team in the same location is not feasible. CE addresses team members being located in differing areas through co-location and having virtual teams. If product development members are not in the same location, virtual teaming allows team members to work together through computers (Crow, 1992). Integrated computer examples used for virtual teams include electronic mail and company-wide computer networks (Turino, 1992). When dealing with customers/suppliers, teams can encounter problems such as a lack of knowledge, adversarial relationships, or time needed for meetings (Maddux & Souder, 1993; Pawar, 1994). A lack of knowledge can cause problems if a supplier's specifications are assumed to be correct, and not checked for accuracy. If the customer specifications are incorrect, the design produced may be unusable. An adversarial relationship that has existed for many years between suppliers and customers can cause difficulties by CE team requirements of having open communication (Maddux & Souder, 1993).

Successful teams are a collaboration of team members rather than conventional design review boards. Team members must accept responsibility for working with each other on projects (Carter & Stilwell-Baker, 1992). Team members need to support and supply information to a product designer (Leech, 1972). Multi-disciplinary team members need to keep internal and external customer needs in mind, listen to and understand each member's opinion, and compromise (Turino, 1992). Effective CE teams are to have open discussion, promote innovative thinking, create more efficient manufacturing processes, have a more satisfied customer, and rely on people's intellect, creativity, and motivation (Crow, 1992).

Providing Concurrent Engineering Team Communication Tools

Team collaboration is an important factor for CE team success (Carter & Stilwell-Baker, 1992). Effective team collaboration requires communicating, sharing information, and having a continuous information flow (Yannoulakis et al., 1991). A communication infrastructure is needed to keep team members abreast of information obtained from CE design component tools (i.e., QFD). The complexity of the product and team affects communication infrastructure needs. A small team may only need electronic mail, whereas a complex project may require an extensive computer database with interactive browsing capability. Team members need to check a wide range of product design technical information through tools such as interactive browsing on product specifications (Carter & Stilwell-Baker, 1992). Computerized tools and links are needed to provide the team members the capability to use shared visual and text information on visual concepts, test results, design alternatives, and design ideas (Mills et al., 1992).

While the use and exchange of computerized information is important, simply exchanging information electronically does not substitute for team meetings (Pawar, 1994). An advantage of virtual CE teams is having a continuous dialog to update the status of the product design by communicating through computer links such as electronic mail or telecommunication. Real-time communication through video conferencing is a tool used by virtual teams. Video conferencing has influenced apparel managers because of its ability to improve efficiency on time, travel, and decision making. The real-time communication allows diverse groups to make collaborative decisions. Levi Strauss and Company and J.C. Penney's have used video conferencing for pre-production and design decisions. Video conference planning sessions have enhanced communication between Gitano, an apparel manufacturer, and Wal-Mart Stores (Browne, 1992).

Team Advantages

Winner et al. (1988) noted that the CE approach improves the efficiency of hard-working people. An overall team benefit is that simultaneous decisions made on plans and actions shorten traditional face-to-face communication and paper communication times (Carver & Bloom, 1991; Shina, 1991). Advantages of teams are improved problem resolution and improved product and process development time (Winner et al., 1988). Team members' use of computer tools allows for quicker problem resolution rather than the traditional mode of communication (e.g., written memo) (Pawar, 1994). The use of multi-disciplinary teams allows for sharing knowledge from team members to other functional area co-workers. Many individuals enjoy working on teams rather than in isolation because a creative individual's interaction on a team may increase the number of creative and productive ideas (Carter & Stilwell-Baker, 1992).

Why Concurrent Engineering is Needed for the Apparel Industry

U.S. apparel manufacturers have been challenged by foreign competition, domestic competition, customer requirements, consumer requirements, and labor intensity of manufacture (Standard & Poor's, 1996). These challenges have been contributors to decreased profits. In the 1990s, apparel manufacturers have felt increased pressure from retail buyers to shorten production cycles, lower prices, and generate more sales growth (Agins, 1994). To meet these pressures and challenges, apparel manufacturers need new approaches to improve profitability and to remain competitive. One approach is for apparel manufacturers to implement CE. The application of CE to apparel design and product development should meet the industry's need to attain a competitive advantage.

Apparel manufacturers need to be more flexible and efficient to provide rapid and cost-appropriate responses to market trends (Adams, 1993). A quick review of CE

conceptual statements indicates that CE could assist apparel manufacturers to meet their goals. The premise of DFM that producibility is designed into a product rather than modified later to correct deficiencies (Crow, 1992) warrants study as a potential process improvement for textile and apparel manufacture. Reducing rework can assist manufacturers to meet cost requirements.

U.S. apparel sales have decreased in the last seven years. Brown (1996) and Standard and Poor's (1996) reported that decreasing apparel sales are in part attributed to consumer dissatisfaction of garment styles that are being offered by the fashion industry. DFQ goals provide an avenue for companies to design a product that meets consumer requirements, consumer desires, and consumer preferences. Redman et al. (1994) reported U.S. retail buyers find more superior quality and detail in foreign-made garments than from American-made apparel products. Identifying quality attributes, eliminating defects, and correcting early product failures prior to shipping the manufactured product are goals of DFLC-R (Birolini, 1993).

AAMA (1994) noted that U.S. apparel manufacturers' traditional methods of calculating cost are no longer appropriate. In traditional apparel cost accounting procedures, allocating costs is called charging to cost centers (J. Paredes, personal communication, January 1996). Inaccuracies can occur when apparel manufacturers arbitrarily assign overhead costs as a percentage of direct labor cost. For an accurate cost evaluation, apparel manufacturers need to look at the effect of total product costs (AAMA, 1994). DFC principles can assist apparel manufacturers in tracking product profitability, capturing total costs of production, and reducing nonvalue-added costs.

Sometimes apparel designers select inferior quality for raw materials in order to reduce a garment's direct cost. However, low cost fabric may have a higher number of fabric flaws. Fabric flaws account for one of the highest percentages of garment rejection at the final inspection (M. Forrest, personal communication, October 1994). Apparel

manufacturers may benefit by making DFLC-I design choices that build quality into a garment rather than inspecting quality out of a garment (e.g., higher fabric quality).

Merkel (1991) described maintainability usage for apparel and textile manufacturers in which separate textile tests are employed to determine serviceability. Apparel manufacturers could benefit by having a holistic approach to product maintainability. Using DFLC-M concepts, a QA supervisor would test combinations of fabric as they are used in the garment design. For example, garment designs with pieced white and blue fabrics should be tested together in order to evaluate textile bleeding and crocking. The current practice is to evaluate each textile fabric separately.

Traditional apparel manufacture process decisions are often made after completion of design and close to production startup. Production managers have autonomy to make interior garment changes; however, for efficient equipment usage, any outside garment changes, even minor ones, need to have designer approval. Often, the approval process for these changes causes production delays (M. Forest, personal communication, October 1994). DFET use of concurrent sharing of information in a seamless, cooperative environment helps manufacturers make quicker product design changes and increases manufacturer flexibility in working with other individuals (Prasad, 1996).

Summary

Manufacturing for U.S. companies has become intensely competitive, unpredictable, and is challenged by inconsistent market growth. Manufacturers, including apparel manufacturers, feel pressure to increase the speed of manufacturing to produce a high quality product at a low cost and to be more responsive to customers (Carver & Bloom, 1991; Committee on Analysis, 1991; Hammer & Champy, 1993; Wheelwright & Clark, 1992). Additional challenges for U.S. apparel manufacturers include addressing

high labor intensity, ease of industry entry, and lower after-tax profits than other manufacturing industries (Standard & Poor's, 1996). The Commission Working Group on the Textile Industry (1989) stated that the primary reason for lack of apparel industry change has been the predominance of small firms with limited financial resources. However, changing business practices is necessary for the survival of all textile and apparel companies (Amacher et al., 1991; Berkstresser & Buchanan, 1986; Moncarz, 1992). Size can no longer be used as an excuse.

Tremendous pressure on manufacturers challenges them to attain a competitive advantage (Porter, 1985). Competitive advantage is the way firms choose and implement strategies such as designing, producing, marketing, delivering, and supporting products. Firms gain a competitive advantage by conceiving new ways to conduct activities, procedures, or technologies (Porter, 1985). Blaich and Blaich (1993) predicted design as the next new way for firms to attain a competitive advantage.

Apparel manufacturers have difficulty transferring some advanced business practices and automation techniques used by other industries because of the uniqueness of apparel manufacturing. The apparel industry must manufacture a product with soft, flexible, and continually changing raw materials. Apparel manufacturers are also challenged by limitations on large production runs, limitations of automated equipment, short product life cycles, shifting consumer demand, and seasonality of product lines (Dickerson, 1991).

Design and product development impact manufacturing more than any other singular process (Wheelwright & Clark, 1992). Sequential manufacturing has traditionally been used for apparel and textile manufacturing (Amacher et al., 1991; Willett & Willett, 1991). In sequential manufacturing, design, product development, production, and distribution are separate functions that do not start without completion of the previous step. Sequential design and product development processes are problematic

and expensive. In sequential manufacturing, decisions made in the conceptual design stage can have costly effects on later processes that require product redesign or return of the product to previous stages for corrections (Menon, 1992b). The creation of poor designs is due often to a designer's lack of knowledge regarding production processes that occur after design (Hayes et al., 1989).

Integrated design processes are needed (Blaich & Blaich, 1993). Integrated design is reported as promoting early and continuous involvement of design from market research through market launch (Blaich & Blaich, 1993). CE shortens product development time by integrating design and production processes (Shina, 1991). CE has provided tremendous success for other industries (Rosenblatt & Watson, 1991). A review of CE literature delineated CE conceptual statements as DFM, DFQ, DFC, DFLC-R, DFLC-I, DFLC-M, and DFET (Crow, 1992; Hyeon et al., 1993). Early in the design maturity stage, the CE conceptual statements act as constraints, to obtain error-free manufacture. CE goals are to (a) consider product use, manufacture, maintenance, and disposal early in the design process; (b) compress overall product development time; (c) reduce cost of development and production simultaneously; and (d) meet or exceed customer needs (Carver & Bloom, 1991; Menon, 1992a). CE uses multi-disciplinary teams. Team members from design, development, marketing, manufacturing, sales, and service work together to develop a high-quality, low-cost product that meets or exceeds consumer needs. Team members make simultaneous decisions on plans and actions to shorten traditional face-to-face communication and paper communication times (Carver & Bloom, 1991; Shina, 1991).

Benefits of CE implementation are designing products right the first time, reducing delays, shortening time-to-market, and creating products with low production costs and high quality (Carver & Bloom, 1991; Shina, 1991). A review of CE literature shows that no applications of CE were found for apparel manufacture. Use of CE is

documented only in durable goods and some consumer goods (i.e., non-apparel) industries (Rosenblatt & Watson, 1991; Syan, 1994, Winner et al., 1988). Current CE models do not address the uniqueness that occurs in the manufacture of apparel because of flexible raw material, variable production, variable product life cycle, and shifting consumer demand. The uniqueness of apparel manufacture suggests that lateral transferability of CE practices is not appropriate. This difference creates a need for a CE framework that is tailored solely to apparel manufacture. This research proposes to create a CE framework geared specifically for apparel manufacture. The literature review leads to the following research question: What is the structure of an integrated apparel product development process using the CE approach?

CHAPTER III. CONCEPTUAL FRAMEWORK

This chapter describes the research frameworks and Integrated Computer-Aided Manufacturing DEFiniton (IDEF) analytic graphic model framework used for data collection and data analysis. The overall research purpose was to develop a CE framework for apparel manufacture. The present study was an interpretational qualitative case study of apparel manufacturers with two phases: Phase One was descriptive and Phase Two was exploratory. Consistent with Marshall and Rossman's (1995) recommendations, a case study approach is appropriate for descriptive and exploratory qualitative studies. The purpose of Phase One was to provide a descriptive documentation that mapped the functional activities of the *as is* apparel design and product development process. The purpose of Phase Two was to create a *to be* environment in which apparel design was integrated with product development using the CE approach. Phase Two research approach was exploratory because CE is new to apparel manufacturers.

Blaich and Blaich's (1993) product design and corporate strategy promote the importance of design management as a formal activity. The goal of design management is for a company to integrate design activities with strategic and operational activities, to coordinate design resources, and to communicate design relevance (Blaich & Blaich, 1993). Integrating design activities is important for companies that want to improve overall profitability (Knox, 1989). The research was unique because CE has shown success in other consumer goods and durable goods industries but is not in current use in the apparel industry.

Concurrent Engineering Process Capture

Process capture is the documentation and verification of an organization's *as is* (i.e., current) environment and is a major step in identifying process improvements and

design accountability (CERC, 1992). This process corresponds to the design management process identified by Blaich and Blaich (1993). The researcher needs to start by evaluating the *as is* environment in order to develop and assess a *to be* environment (CERC, 1992; Jayaraman, 1990). Pawar and Driva (1996) recommended that a researcher begin evaluating the *as is* environment by tracking an organization's work flow. Tracking work flow allows an individual to identify the major weaknesses in an organization's existing system. A company's *as is* environment evaluation is a starting point for assessing and developing a *to be* environment (Jayaraman, 1990). Once an individual recommends changes for a *to be* environment, formalized business processes can be improved. Using a CE approach, Pawar and Driva recommended that the steps in process capture should be to (a) review product development literature methodologies, (b) develop a questionnaire and interview approach, (c) interview to analyze the gap between the *as is* and the *to be* environment, (d) analyze data, (e) identify how change could be achieved, and (f) formulate and verify the CE framework. The researcher used analytic graphic models for data collection and for data analysis. Analytic graphic models include flowcharts, IDEF diagrams, and functional requirement diagrams (Blanchard et al., 1995). Analytic graphic models are used to diagram a set of interrelating variables that have a suggested relationship or direction to represent a whole system or part of a system. Analytic graphic models are not designed to provide mathematical results; however, they can be a preliminary step in developing a mathematical model (Malhotra, 1993).

Review Product Development Literature Methodologies

For the present study, the researcher reviewed engineering design process theory, product development models, and CE literature to guide data collection and analysis. The researcher used engineering design process theory as a basis for data collection of the *as is* environment apparel design activities. During data analysis, the researcher's use of the

engineering design process facilitated organization and analysis of the current design activities.

Phase Two data collection was supported by the researcher's review of published CE analytic graphic models. To develop CE conceptual statements and CE operational statements, the researcher reviewed CE analytic graphic models and CE literature. The researcher used IDEF analytic graphic modeling to diagram the results of the *as is* and the *to be* environments.

Engineering Design Process Conceptual Framework

Phase One research was supported by engineering design process theory that conceptually describes the design process. Engineering design process theory, documented by Jones (1973), Leech (1972), and Lewis and Samuel (1989), was used to develop questions for Phase One interviewing. The engineering design process theory was used as a guide to interview apparel associates involved in the design process. Lamb and Kalall (1992), Orlando (1979), and Watkins (1988) have indirectly used engineering design process as part of their frameworks for their published apparel design process models.

Engineering design process conceptual framework has the following phases: problem recognition, problem definition, problem exploration, search for alternatives, evaluation and decisions, solution specification, and solution communication. The engineering design process and its use in the apparel design process are detailed in a forthcoming article entitled "Applicability of the Engineering Design Process Theory in the Apparel Design Process" by Regan et al., (in press) (see Appendix A for abstract).

Product Development Models

In addition to the apparel design activities, the researcher included product development activities in the present study (see Figure 2). Apparel product development activities are outside the realm of the engineering design process framework. With the

qualitative research method, a researcher is allowed to build a conceptual framework from information gathered during data collection (Strauss & Corbin, 1990). During data collection, the researcher used company product development line calendars and the Glock and Kunz (1990) model (see Figure 4) to provide a beginning structure for interviewing.

Analytic Graphic Concurrent Engineering Models and Concepts

The purpose of interpretational qualitative analysis is to identify themes, determine essential features, and propose conceptual statements. To identify themes, a researcher can use existing concepts and theories to categorize the data (Tesch, 1990). The researcher interpreted CE analytic graphic models to use for the foundation of Phase Two's development of a generic CE apparel model. To develop themes for the CE apparel framework, the researcher identified CE conceptual statements from CE literature and from published CE analytic graphic models by Crow (1992), Hyeon et al., (1993), Schmitz and Desa (1992), Sharon (1992), and Turino (1992). To organize and provide breadth for the CE conceptual statements, the researcher identified CE operational statements from CE literature (Blanchard, 1995; Boothroyd, 1992; Carter and Stilwell-Baker, 1992; Carver & Bloom, 1991; Crow, 1992; Duffey & Rosen, 1994; Ehresman et al., 1991; Maddux & Souder, 1993; Menon, 1992a; Shina, 1991; Syan, 1994). There are multiple synonymous CE phrases identifying CE conceptual statements. Some common CE conceptual statements are design for X (e.g., design for manufacturability), design parameters, design constraints, and design requirements. The CE analytic graphic models illustrate that CE conceptual statements are used by a design team to consider a product's design process. The CE design process refers to a design team's consideration of issues on product manufacturability (Crow, 1992).

The CE design component model by Crow (1992) and Hyeon et al. (1993) illustrate that CE conceptual statements (i.e., components) have equal importance to create

a holistic integrated product and process design (see Figure 8). The researcher's review of CE literature identifies that the most common CE conceptual statements are design for: manufacturability (DFM), quality (DFQ), cost (DFC), life cycle-inspectability (DFLC-I), life cycle-reliability (DFLC-R), life cycle-maintainability (DFLC-M), and enabling technology (DFET). DFM, DFQ, and DFC are CE conceptual statements that specify a product design's producibility, customer requirements, and cost requirements (Crow, 1992; Ehresman et al., 1991). DFLC-I, DFLC-R, and DFLC-M are CE conceptual statements that identify design process issues for test and inspection, a product's functionality, and a product's restoration (Blanchard et al., 1995; Crow, 1992). DFET conceptual statements tie the pieces together through the concurrent sharing of information in a seamless, cooperative environment (Prasad, 1996).

An important part of CE is the incorporation of teams and the use of enabling technology (Crow, 1992). Phase Two data collection included CE team goals, team requirements, and enabling technology. The researcher reviewed CE analytic graphic models and CE literature that described teams and enabling technology requirements. The information on CE teams and enabling technology was used to create the questionnaire.

CE implementation is represented by a team-based or a computer-integrated approach. A team-based approach has wider industry adoption and may have easier implementation than computer integration (Hyeon et al., 1993). Many CE analytic graphic models include computer integration (Crow, 1992; Hyeon et al., 1993; Schmitz & Desa, 1992; Sharon, 1992). Some CE analytic graphic models represent computer integration with dashed lines (Schmitz & Desa). Other model authors provide a narrative description versus computer integration drawn in the model (Hyeon et al., 1993; Sharon, 1992, Turino, 1992). Schmitz and Desa contend that computer integration is necessary for an organization to actually save labor, cost, and time through CE implementation. Computer integration was limited in the present study. The computer integration was limited

because: (a) the research project was a CE team-based approach, (b) the apparel industry has high labor intensity with low technology when compared to other industries, (c) some computer information structures are not applicable in an apparel environment due to apparel manufacture uniqueness, (d) the exploration of enabling technology with computer integration is new for apparel manufacturers, and (e) computer-based CE implementation was beyond the scope of this research.

Develop Questionnaire and Interview Approach

The next process capture step is to develop a questionnaire and interview approach (Pawar & Driva, 1996). In the present study, the researcher used qualitative research methods for data collection. Primary data collection methods for qualitative research are for the researcher to participate in the setting, to observe, interview, or review documents (Marshall & Rossman, 1995). For the present study, the researcher interviewed, observed, and administered focus group questionnaires as the primary means to obtain information. An overriding goal of qualitative research is for the researcher to discover new relationships among relevant categories to combine categories in new ways (Strauss & Corbin, 1990. The qualitative research approach is congruent with Pawar and Driva's approach of combining general CE information with company-specific information.

Analysis of Gap Between the *As Is* and the *To Be* Environments

A researcher compares an organization's current mode of operation with a future environment in order to analyze the gap between the *as is* environment and the *to be* environment (Pawar & Driva, 1996). The first step in creating a *to be* framework is for individuals to evaluate what needs to change in the *as is* environment (Prasad, 1996). CERC (1992) recommends that individuals within an organization study their *as is* product development process to determine how to change an organization's *as is* environment to become a *to be* environment using CE. The goal of evaluating the *as is*

environment is to reorganize, streamline, or eliminate redundant activities. A researcher can use workbench tools to determine the requirements needed or constraints occurring in an *as is* environment (Pawar & Driva). Performance measurement is one type of workbench tool. Time-to-market, cost, and process quality are specific types of performance measurements used to evaluate a process (Duffey & Rosen, 1994). In the present study, the researcher evaluated performance of the *as is* environment by identifying nonvalue-added activities. Apparel associates evaluated potential process improvement for time-to-market, cost, and quality in the *to be* environment.

Analysis of Data–IDEF

Pawar and Driva (1996) indicated the next step is to analyze data. For the present study, the researcher used Marca and McGowan's (1988) Structured Analysis and Design Technique (SADT) as the conceptual framework to analyze data on the *as is* environment. Marca and McGowan's SADT conceptual framework was adapted for data analysis during Phase Two. SADT was developed in the 1960s and was the precursor to Integrated Computer-Aided Manufacturing Definition (IDEF). Since the 1980s, the acronym IDEF is more commonly used in engineering literature than the acronym SADT (Marca & McGowan). Henceforth, the acronym IDEF will replace the usage of the acronym SADT.

IDEF is an analytic graphic modeling framework. Jayaraman (1990) indicated the analytic graphic modeling suitable for describing a detailed activity process is $IDEF_0$. $IDEF_0$ function modeling is useful in providing guidance in data collection and to diagram results of a detailed process. There are three IDEF modeling methods: $IDEF_0$, $IDEF_1X$ and $IDEF_2$. A researcher can use $IDEF_0$ to diagram the hierarchy of activities that comprise an enterprise's activities. The $IDEF_1X$ model focuses on an information structure that supports functional activities within an enterprise. The $IDEF_2$ dynamic

model is used to represent time-dependent characteristics. Malhotra and Jayaraman (1990) showed the appropriateness of using IDEF to diagram results for an apparel manufacturing study. The researcher used Jayaraman's recommendations for the IDEF model type appropriate to this present study as the $IDEF_0$ function model since the study's focus is on activities occurring within a system.

IDEF framework is a distinctive analytic graphic modeling approach in that it represents a hierarchical structure. An $IDEF_0$ model is developed with a specific purpose and a viewpoint. The purpose of Phase One $IDEF_0$ diagramming was to document the current *as is* apparel design and product development process for use in identifying the sequential flow and process performance. The purpose of Phase Two $IDEF_0$ diagramming was to create an integrated apparel design and product development process using the CE approach. A viewpoint is drawing a model from one perspective. The viewpoint for the present study was from a Ph.D. student/analyst perspective and was based on interviews of representatives from actual apparel manufacturing firms.

Identify How Change Could be Achieved

Pawar and Driva (1996) stated that the next process capture step is to identify how change could be achieved. Carter and Stilwell-Baker (1992) indicated that CE implementation needs a starting point in order to improve the product design process and as a company implements CE, the process will continually improve. Following Carter and Stilwell-Baker's and Pawar and Driva's recommendations, the researcher used performance measures to guide interview questioning on what needed improvement in the *as is* environment. During Phase One, the *as is* apparel design and product development work flow was mapped to identify major performance weaknesses (e.g., time-to-market, cost, process quality) in the existing system. To analyze the gap between the *as is* and *to be* environments requires the use of appropriate workbench tools. Workbench tools are

an effective method for an individual to identify organizational requirements and constraints. Performance measurement is one type of workbench tool (Pawar & Driva). Three performance measurements that have been used to evaluate product market success are time-to-market, cost, and process quality (Duffey & Rosen, 1994).

During Phase One, the researcher explored what performance measures were used in the *as is* environment. The researcher used Duffey and Rosen's (1994) conceptual performance measure definitions of time-to-market, cost, and process quality to help guide data collection. The following summarizes Duffey and Rosen's review of performance measures. Time-to-market delay is any activity or group of activities that are created by deviating from within a pre-established and designated time allotment; hence, a product would not reach the market when expected. A time-to-market delay may be a result of nonvalue-added activities or rework. An output of a functional activity is classified as nonvalue-added or rework if work existed prior to the functional activity and work could not proceed without correction. Time-to-market delay can cause lost revenue due to late entry, opportunity cost loss, or delayed payback for equipment investment. Cost is defined as a product's unit manufacturing cost plus the addition of management level cost evaluation. Quality attributes are categorized into manufacturing process quality and perceived quality. Manufacturing process quality is defined as design attributes that affect a manufacturing process that limit scrap, rework, and inspection. Perceived quality is defined as the quality of user performance, service, and maintenance.

In the present study, the researcher queried apparel associates on time-to-market, cost, and process quality performance in the *as is* environment. The researcher analyzed qualitative measures of time-to-market, cost, and process quality because the data showed that quantitative measures were not used by the sample in measuring design and product development performance. The qualitative research approach allows a researcher to

determine what research categories will emerge or to determine whether a category exists in the data (Strauss & Corbin, 1990).

For Phase Two, published CE frameworks helped to provide a structure to identify the necessary changes in an organization to create a CE environment. To identify change, the researcher designed data collection instruments to develop a CE apparel framework. To create the CE framework, the researcher wanted to address what CE conceptual statements and operational statements were applicable for apparel design and product development. To refine the CE model, the researcher wanted to determine how apparel functional activities would be reorganized to create a CE environment.

Formulate and Verify the Concurrent Engineering Framework

The final stage of process capture is to formulate and verify the CE framework (Pawar & Driva, 1996). The researcher used qualitative research methods for research validity and reliability. Miles and Huberman (1994) indicate that qualitative research reliability and validity rely on the researcher's professional judgment. Specific characteristics of good reliability and validity in a qualitative study are the researcher's (a) familiarity with the phenomenon being studied, (b) strength of conceptual interest, (c) use of a multi-disciplinary approach, and (d) strength in investigative skills. In the present study, internal validity and reliability was reinforced by using triangulated data collection and by interviewing multiple subjects from cross-functional areas. Triangulation is a researcher's use of multiple sources of data to evaluate support of a finding (Marshall & Rossman, 1995; Miles & Huberman).

Marca and McGowan's (1988) validation process was the validation procedure used in the present study. Marca and McGowan's validation guidelines are for a reader to study the diagrams, review diagram results, and verify that diagrams are accurate from the person's perspective who uses the system.

Research Question

In the 1990s, apparel and textile industries face intense domestic and international competition. Low after-tax profits are typical for U.S. apparel manufacturers and have contributed to the need for companies to explore new competitive advantages (Standard & Poor's, 1996). Having superior design is predicted to be important for companies to achieve a competitive advantage (Blaich & Blaich, 1993). CE's use in other industries has been tremendously successful and has substantially improved the design of products (Rosenblatt & Watson, 1991). By having simultaneous design and production considerations, CE implementation lowers cost, shortens time-to-market, and meets consumer needs (Rosenblatt & Watson). Apparel manufacturers can benefit from such savings; therefore, this process should have potential for providing apparel manufacturers with new competitive advantages.

A review of literature has shown that CE is not in current use by the apparel industry. The uniqueness that occurs in the manufacture of apparel, including flexible raw material, variable production, variable product life cycle, and shifting consumer demand, is not addressed in current CE models. This uniqueness of apparel manufacture suggests that lateral transferability of CE practices is not appropriate. This research fulfills a need to create a CE framework designed specifically for apparel manufacture. This need led to the following research question: What is the structure of an integrated apparel product development using the CE approach?

CHAPTER IV. METHODS

Introduction

The present study was an interpretational qualitative research design that included a triangulated data collection method that combined interviewing, reading company documents, observing, and giving questionnaires to focus groups. Apparel associate focus groups validated the present study's results. This chapter describes the research design, sample characteristics, data collection method, and data analysis. The research project had two phases of data collection. Phase One data collection documented the *as is* environment. Phase Two data collection consisted of giving questionnaires to apparel associate focus groups who reorganized existing apparel design and product development activities to develop a *to be* environment, using the CE approach.

For the present study, the researcher wanted to develop a comprehensive map of the current (i.e., *as is*) product development process. It was necessary for the researcher to understand process performance challenges during Phase One so that an improved process could be developed during Phase Two.

Qualitative Research Design

The present study's research design is interpretational qualitative analysis. Qualitative research studies are classified into two categories: structural analysis and interpretational analysis. Interpretational analysis is descriptive research where the researcher focuses on problem solving, discovers data patterns, or understands the meaning of phenomena (Tesch, 1990).

Successful qualitative research is dependent on a researcher acquiring an in-depth understanding of the research setting (Patton, 1980). Qualitative research typically starts by observing inductive events. Using an inductive approach in the present study allows the researcher to synthesize patterns of everyday events. Noted important by Patton, the

researcher does not select study dimensions in advance. For example, the researcher does not impose preexisting expectations on a situation, manipulate the research setting, set main variables, or establish hypotheses. Not imposing preexisting expectations is important to synthesize patterns among the activities performed by the subjects, thereby mapping a generic apparel design and product development process.

Sample

A goal of qualitative research is to study events that explain categories in which the researcher develops new conceptual relationships. Marshall and Rossman (1995) support a case study approach for research that is designed to develop conceptual relationships. For this reason, a case study approach was used in the present study to develop in-depth design and product development conceptual relationships.

The current study used a purposive discriminate sample to obtain an in-depth study of apparel design and product development. Patton (1980) noted that a purposive sample is useful when a researcher's goal is to penetrate the research setting. A purposive discriminate sample is a researcher's predetermined selection of sites, individuals, and type of data collection (e.g., interviews, observations). Researcher predetermination includes document types and subject contact types that will be used in the research. The researcher may choose to focus on one individual over time or may interact with different individuals at varying points during a pre-established time span (Strauss & Corbin, 1990). In the present study, the researcher interacted with multiple apparel associates during which several seasonal design and product development cycles (e.g., spring, fall) were simultaneously occurring. The product development line calendars were arranged so that during any given week, apparel associates were working on multiple seasons. The researcher interacted with apparel associates and collected data during one complete seasonal design and product development cycle from start to finish.

Criteria for Company Sample Selection and Selection of Sites

For the study, the researcher set the following sample criteria: (a) product development individuals located at company headquarters or the manufacturing site, (b) companies located within a reasonable driving distance from the researcher to allow for numerous on-site visitations, (c) companies representing non-competing apparel manufacturing segments, and (d) companies willing to participate in the study.

Finding a sample for a case study required (a) a background information search, (b) phone calls to apparel companies, (c) letters of introduction, (d) visits to apparel manufacturers, and (e) a presentation of the research proposal. Obtaining a sample took the researcher five months from initial contact through manufacturer approval. The researcher conducted a background information search by going to the Virginia Polytechnic Institute and State University library to read publications about apparel manufacturers and to obtain information about apparel companies. The researcher read background information on public and private apparel companies within the region. A number of companies were reviewed. Apparel manufacturer addresses were obtained from the Virginia Industrial Directory (1994) and from Virginia, North Carolina, Pennsylvania, and Maryland phone books. The researcher called Human Resource Directors to inquire whether apparel companies, which were contacted met the criteria for sample selection. Some apparel manufacturers were resistant to participating in the case study research, while others were interested but did not meet the sample criteria. The researcher then sent a letter of introduction to the apparel companies with a request to visit the company. Some apparel company contacts requested confirmation of the researcher's student enrollment at a university, and this was supplied. If a company was interested, the Human Resource Director provided the name of a company executive who would be the contact person. The researcher contacted the contact management executive to obtain permission to involve the company in the research project. The researcher met with a

manager or group of managers to discuss research specifics, goals, and company involvement. The meeting with contact managers focused on company benefits and responsibilities. The researcher explained participation benefits, anticipated data collection, estimated number of contacts with company individuals, interviewee requirements, and noted the other companies that were participating in the research (see Appendix B for research relationships with people and companies). The researcher expressed flexibility in working within the company's and individual's schedules. When a verbal agreement was reached and criteria were met, a company was selected as part of the sample. Confidentiality agreements were requested and signed by both the apparel companies and the researcher.

Sample Profiles

The sample was located in the Southeastern United States. Apparel manufacturing is a major industry in this region (Dickerson, 1991; Redman et al., 1994). Data collection took place at company headquarters and manufacturing headquarters. The firms and selected suppliers or customers in the sample collectively represented five states: Alabama, New York, North Carolina, Virginia, and Wisconsin.

The apparel manufacturers' sample represented multiple merchandise classifications and several organizational structures. To increase representation of the apparel industry, the sample represented the three major segments of the apparel industry (i.e., men's, women's, children's). The Standard Industrial Code (SIC) codes represented in the sample were 2360, 2325, 2321, 2253, and 2330. In 1993, the combined national employment for apparel manufacturers with these SIC codes was 255,124, and the number of establishments was 2,588 (U.S. Department of Labor, 1994b). In 1993, these SIC codes represented 25% of total apparel manufacturing employment and 9.8% of the total number of establishments within the total SIC classification. The companies were more willing to participate in the research study by

having other participating companies that produced noncompeting products (i.e., differing merchandise classifications) rather than working with companies who were their direct competition. While the SIC merchandise classifications differed, the apparel design and product development process was similar within the sample.

Research breadth was enhanced by having multiple organizational structures which created a broader viewpoint for a generic design and product development process. The company organizations represented vertically integrated manufacturing, non-vertically integrated manufacturing, and production in company-owned manufacturing facilities or production in independent contracting facilities. The apparel products represented were produced domestically. The products were produced with exclusive textile finishes (e.g., dye or print) for a manufacturer or for a mail order company, or made with wholesale converted fabric.

Company A is an apparel manufacturer with four Strategic Business Units (SBU) and an approximate annual production volume of 2.2 million units. The company is owned by a domestic public corporation and produced garments in company-owned domestic facilities and with international contractors. The researcher interviewed product development personnel at company headquarters and manufacturing personnel in company-owned domestic plants. The process of designing, sourcing, and producing goods with international contractors was not included in data collection. The products sold were a durable mid-price range product with high brand recognition. The company worked closely with suppliers to develop new seasonal coloration and developed fabrics, but is not vertically operated. All design and product development personnel were located at the company headquarters. The company is responsible for its own fabric converting.

Company B is an apparel contractor that produced the majority of its product yield for an independent, domestic mail order firm. The manufacturing company's approximate annual production volume is 720,000 units. The company is a vertically integrated

operation from the purchase of yarn through product distribution. The manufacturing process included back-twisting yarns, griege-good knitting, assembling, dyeing, finishing, and distributing the product. The product is domestically produced and had a unique niche in the knitwear industry through the type of machine operation utilized by the company. The company is privately owned by a domestic corporation. Design, merchandising, and marketing personnel were employed by the primary wholesale customer (i.e., independent mail order firm). The orders from the primary wholesale customer included design sketch, order request, and numeric order commitment. Product development individuals worked for the apparel manufacturer at the manufacturing site. Some positions were duplicated between the manufacturer and the primary wholesale customer (e.g., quality assurance).

Company C is one SBU for a domestic apparel manufacturer. Contributing approximately 10% of annual company sales, the SBU's approximate annual production volume is four million units. The company is owned by a domestic public corporation. The SBU produced a basic product with product variation being dependent on developed fabrics and fabric finishes. The company is not vertically integrated and individuals in the SBU worked closely with textile suppliers for the fabric-converting process in producing new seasonal coloration, developed fabrics, and finishes. Manufactured goods were a durable, mid-price range product with high brand recognition which were produced domestically and internationally. The researcher interviewed product development personnel at company headquarters and manufacturing personnel in a company-owned domestic plant. The process of sourcing and producing goods with international contractors was not included in data collection. All product development personnel were located at the company headquarters. The SBU did not have an apparel designer who was employed by the company; rather, the merchandiser is responsible for design functions.

Occasionally, a design consultant worked with the SBU. The design consultant acted as an independent contractor and worked away from the company headquarters.

Supplier and customer participation. Sixteen personnel from three textile suppliers and one wholesale customer participated in the research project that worked with one of the three apparel manufacturers. Textile supplier A produced knit piece-dyed, yard goods for Manufacturer A in 100% cotton and cotton-blends. Textile supplier B produced 100% cotton and cotton-blend printed knit fabric for Manufacturer A. Textile supplier C is a woven and knit print goods supplier that produced woven printed fabrics for Manufacturer C. The primary wholesale customer worked closely with Manufacturer B to supply design and product development information.

Criteria for Subject Selection

For each of the three apparel manufacturing companies in the sample, the subjects interviewed were those actively involved in design, product development, or sample apparel manufacture. Henceforth, subjects are identified as apparel associates. The researcher requested interviews with participants who were involved in design and product development. The subjects who participated in the study were selected by the contact management executive. The companies had varying numbers of apparel associates involved with design and product development. The numbers varied due to organizational culture, the type of product produced, and internal product development organization (e.g., whether the company converted their own fabric).

How Subjects Were Contacted

The contact management executive selected and contacted customers or suppliers to enlist participation in the research project. A follow-up letter was sent by the researcher with information about the research project. For interviews, the researcher contacted the contact management executive to arrange for on-site interviews. A follow-up letter (i.e., fax, electronic mail, letter) was sent to the contact executive requesting interview times.

The contact executive contacted the subjects and arranged the interview appointments. Each apparel associate signed an informed consent form for participants of investigative projects at the first interview meeting (see Appendix B for research relationships with people and companies).

Consistently and systematically gathering data on each category is important for qualitative studies (Strauss & Corbin, 1990). To achieve consistency on collecting data, the researcher contacted the contact executive to interview apparel associates who were responsible for specific job functions in the design and product development process, regardless of job titles. Generic job titles are used in the study's results. Design and product development job titles are listed in the $IDEF_0$ glossary section (see Appendix C for $IDEF_0$ glossary).

A researcher needs to match who is interviewed with the research question (Rubin & Rubin, 1995). As recommended by Strauss and Corbin (1990), for the present study the researcher used a discriminate sampling procedure in which conscientious choices on who and what to sample were made. The researcher's objective in using discriminate sampling was to verify the process being studied and to fill in underdeveloped areas. The researcher incorporated triangulated methods of interviewing and observing apparel associates to control bias in using the discriminate sampling method. Triangulation combines multiple sources of data on one single topic and strengthens the data analysis for other research projects. One method of research triangulation is to interview multiple individuals on the same topic (Marshall & Rossman, 1995). The researcher determined that interviewing multiple sources would have a broader research perspective and less interview procedure bias versus obtaining only one person's opinion. If more than one apparel associate was available for a specific function (e.g., Pattern Maker), multiple apparel associates were interviewed and observed. If individuals had duplicate roles in a

company (e.g., more than one designer), the key management executive selectively assigned an apparel associate who was available during that site visit and was responsible for a particular function. As multiple site visits were made, all design and product development individuals participated in at least one interview.

Sample Size

Apparel associate positions and the number interviewed during Phase One and Phase Two are shown in Table 1. The total sample size was 72 subjects. As shown in Table 1, Phase Two had a smaller sample size (N=36) than Phase One. The contact management executive selected apparel associates who were deemed most knowledgeable about a specific process (e.g., Marker Maker). Thirty-six of the initial apparel associates did not participate in Phase Two. All of the apparel associates knew their segment of the *as is* environment process; however, some apparel associates were not aware of all steps that take place during design and product development. The apparel associates' lack of broad knowledge did not affect the present study's results because the researcher was able to bring together the *as is* process steps by the knowledge gained in interviewing multiple apparel associates.

The researcher determined during initial Phase One interviews that some apparel associates lacked the necessary holistic design and product development background to respond to questions on improving the process for Phase Two. During Phase One, the researcher found that designers and merchandisers had the most holistic knowledge of the current *as is* process. Thus, discriminate sampling criteria were refined during Phase Two to include individuals who understood the entire *as is* environment and who represented a functional area (e.g., Pattern making). Some apparel associates who had knowledge of the process were not available for Phase Two interviewing. If these apparel associates were not available, an alternate representative (e.g., Vice President, Manufacturing) who met the discriminate sampling criteria was interviewed. The alternative representative was

selected by the contact executive. The use of alternate representatives did not affect the results' outcome because the people who were selected had holistic knowledge of the *as is* environment and were experts in the area being represented (e.g., manufacturing). Specific survey sample size is noted in the questionnaire administration section.

The qualitative sampling criteria specified by Miles and Huberman (1994), Tesch (1990), and Strauss and Corbin (1990) were followed in the present study. Qualitative studies frequently have a limited number of subjects and use a purposive sample. Achievement of qualitative sampling validity relies on the researcher to set a boundary, to use categories or a frame, and to be theory-driven (Miles & Huberman; Tesch). Setting a boundary means the researcher has defined limits that directly relate to the research question. A frame, or categorizing the data, is a process that a researcher uses to uncover or confirm a study's primary constructs. Using sampling techniques that are theory-driven means that the researcher must look for the frequency of occurrence and determine how widely an interviewee's perspective is shared among a group (Miles & Huberman). The goal was for the researcher to achieve saturation for each category (Strauss & Corbin).

The researcher set the boundary as the apparel design and product development process in the present study (see Figure 1). The researcher focused on the process steps in the design and product development process and interviewed multiple subjects to uncover the primary constructs in the present study (see Table 1). Validation of the results by apparel associates provided a group perspective.

Table 1

Sample by Generic Position Title and Number Interviewed

Subject	Phase 1	Phase 2
Apparel Designer	5	5
CAD Artist–Apparel and Textile	2	2
Cost Engineer	2	1
Cutting Room Manager	1	0
Director, Merchandise Services	0	1
Division Engineer	2	1
Fabric Buyer and Assistant	3	0
Forecast Associate	2	1
General Merchandise Manager	5	5
Knitting Manager	1	0
Marker Maker	1	0
Marking Supervisor	1	1
Merchandise Associate	2	0
Pattern Maker	5	2
Plant Industrial Engineer and Assistant	3	0
Plant Manager	4	1
Product Engineer	3	3
Production Line Supervisor	2	0
Prototype Operator	1	0
Prototype Supervisor	1	1
Quality Control–Piece Goods and Garment	4	1
Research and Development Manager and Assistant	2	2
Sample Issue Coordinator	1	0
Sample Supervisor	2	0
Sewing Line Supervisor	1	0
Specification Writer	2	1
Textile Account Representative	2	3
Textile Colorist	4	0
Textile Plant Manager and Supervisor	4	0
Textile Technical Design–Engraving	4	1
Vice President, Engineering	0	1
Vice President, Product Line	0	1
Total	72	34

Data Collection and Data Analysis

The research study consisted of two major phases. In Phase One, the functional activities of the *as is* environment were mapped. The researcher referred to reviewed

literature on the design and product development process as a guide for data collection. The researcher referred to engineering design process theory to guide design process (Jones, 1992; Lewis & Samuel, 1989; Medland, 1992; Middendorf, 1969). The researcher referred to Frings (1994), Glock and Kunz (1990), and Kadolph et al. (1993) for apparel and textile design and product development information. Data from this phase was used to establish a baseline and to provide information for Phase Two, the development of an integrated apparel design process using the CE approach. The development of a generic CE apparel framework was obtained by blending across-company design with product development information.

Phase One data collection was a triangulated method that combined interviewing, reading company documents, and observing. Phase Two data collection consisted of the researcher interviewing and giving questionnaires to apparel associate focus groups. Data analysis for Phase One and Phase Two included steps for authoring, distributing, validating, and gaining approval. The authoring cycle involved transcribing audiotapes, de-contextualizing transcript data, re-contextualizing transcript data, and analyzing documents. The data were then re-contextualized into $IDEF_0$ diagrams. The researcher compiled drawn $IDEF_0$ charts into small kits during the distribution stage. The apparel associates reviewed and validated the *as is* environment and the *to be* environment during the validation stage. The gaining approval stage involved $IDEF_0$ chart review and approval by Ph.D. committee members.

Preparation for Interviewing and Model Development

To prepare for data collection, the researcher reviewed literature, conducted pilot interviews, and toured apparel manufacturers from October 1993 through August 1994. The individuals who were interviewed and observed during background development were not part of the research sample. A review of literature indicated that line

development calendars were used as guides in apparel product development scheduling (Glock & Kunz, 1990). Apparel companies use this calendar as a guide for the sequential design and product development process. However, it is an *ideal* schedule that does not track delays in the process. Additionally, the calendar does not account for expedited orders or product designs rushed through the process.

Eighteen individuals representing eleven different apparel companies were interviewed or observed during background development. During July and August 1994, five apparel designers were interviewed about design inspiration and line development. One merchandise manager was interviewed August 1994 about merchandising responsibilities. A production pattern manager was interviewed for pattern department productivity analysis February 1994 through May 1994. Information about the manufacturing of samples and full production was obtained through observing and interviewing the plant managers from four apparel manufacturing contractors and two apparel manufacturers. Plant visits included interviewing plant managers, personnel managers, production managers, industrial engineers, and a scheduling manager. Costing information was obtained by interviewing two industrial engineers. Industrial engineering interview questions were based on manufacturing sewing sequence and labor cost information. Textile development information was attained from a tour of two textile dyeing and finishing facilities.

Phase One: Mapping of Functional Activities of the *As Is* Environment

Data collection for interpretational qualitative research is an ongoing process of data collection and data analysis. Phase One and Phase Two data collection and data analysis combined Tesch's (1990) and Marca and McGowan's (1988) IDEF data collection and data analysis methods to acquire information needed to create the analytical

$IDEF_0$ diagrams. The IDEF phrases used by the researcher in the present study are consistent with IDEF published literature (Marca & McGowan; Materials Lab, 1981). The IDEF phrase for a complete set of diagrams is IDEF model; whereas, the phrase IDEF diagrams is used when a researcher refers to a portion of an entire IDEF model. The $IDEF_0$ model was created through interviewing, authoring, distributing, validating, and gaining approval of the results.

Interviewing

The interviewing process followed Tesch's (1990) and Marca and McGowan's (1988) methods. The interview procedure steps were (a) preparing for the interview, (b) interviewing apparel associates, and (c) observing apparel associates.

Preparing for the Interview

The line development calendar and related company documents were reviewed to familiarize the researcher with the specific company characteristics and to generate specific interview questions for each company prior to conducting the interviews. Reviewing company documents helped the researcher develop flowcharts and prepare for multiple interviews with apparel associates. A flowchart is a useful tool when a person wants to identify ways to improve a process (Walton, 1986). Some flowcharts (e.g., analytic graphic diagrams) were developed prior to interviewing and helped the researcher guide and focus apparel associates on an interview topic. The flowcharts used in data collection identified activities and the sequence of a specific product development process. Flowcharts were developed by extracting information from reviewed literature, phone conversations, company documents, and background development. A flowchart has standard symbols for describing the starting point, ending point, tasks in a process, decision points, and flow direction (Ehresman et al., 1992).

During Phase One interviewing, the flowcharts were useful in showing apparel associates the logical sequence of a specific process, developing fabric prints, for example see Figure 12.

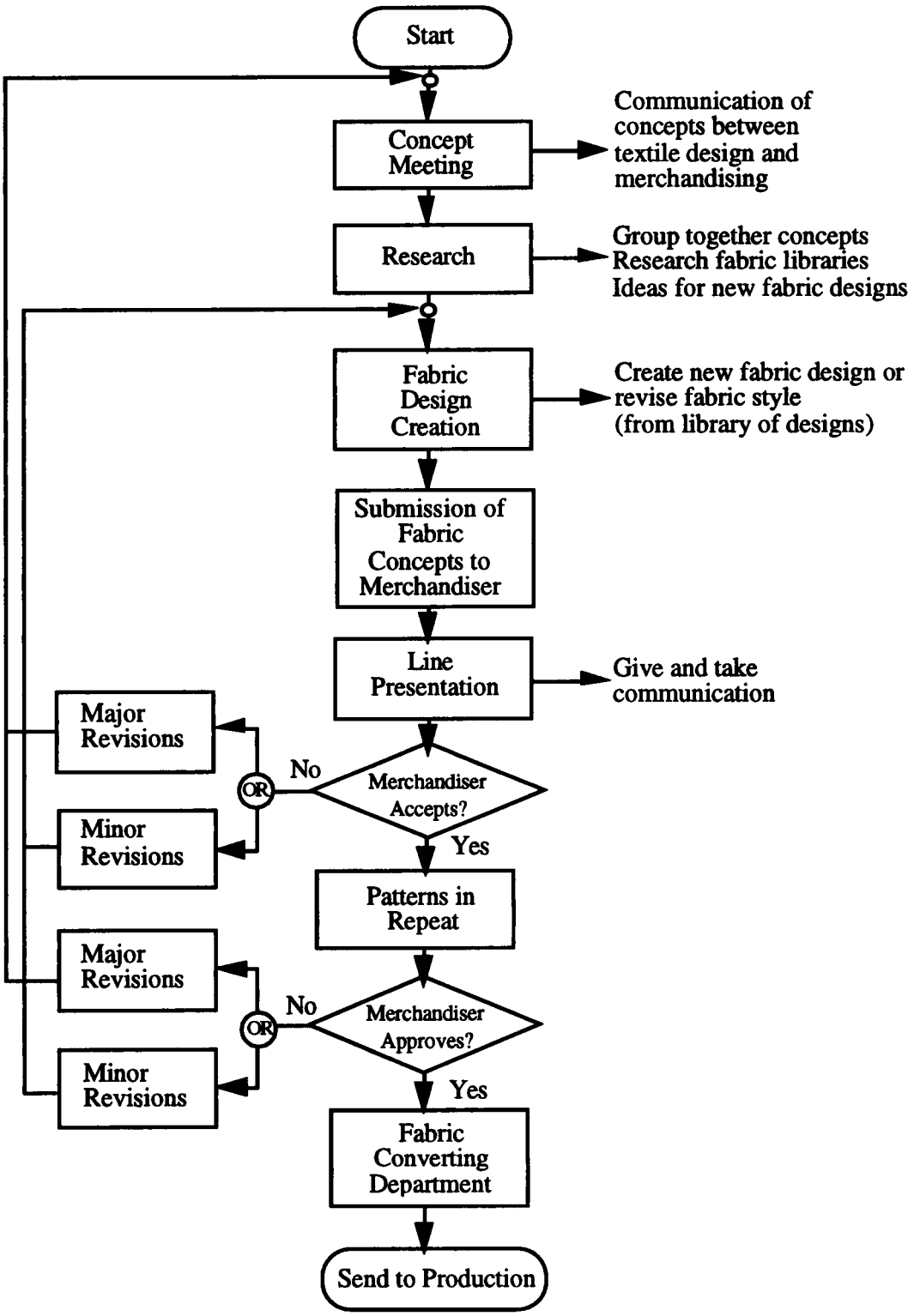


Figure 12. A flowchart for data collection: Developing fabric prints.

Interviewing the Subjects

The purpose of interviewing was to gain information from an apparel associate's perspective. In certain instances, a qualitative researcher's goal is to actually experience the environment of the individual being interviewed (i.e., get into a person's head) (Patton, 1980). Phase One used a flexible interview approach. A flexible interview is the use of an interview guide; however, the researcher does not limit the interview solely to those questions on the guide. Additional questions could be added based on interviewee response from previous questions. The researcher felt that a flexible interviewing process was important during Phase One for the following reasons: (a) the apparel associate was not limited to the information he/she could provide, (b) beginning research stages were exploratory and probing was important, (c) the sequence of questions regarding the functional activities could be adjusted to match the sequence of a company's events, and (d) the approach allowed the researcher to gain an in-depth understanding of design and product development.

As recommended by Malhotra (1993), flowcharts were used by the interviewer to guide interview questioning and to focus the interviewee on the topic. The researcher directed the apparel associate to areas in the diagram inquiring about each stage. Flowcharts were flexible, and the researcher adapted the interview process based on an apparel associate's answers to previous questions. Apparel associates were asked to comment on specific product development processes diagrammed in flowcharts. The researcher found that some apparel associates were not familiar with flow diagrams and preferred answering the questions without diagrams. In these instances, the researcher relied solely on interview questions.

Phase One interviews were conducted from February 1995 through June 1995. Interviews were conducted at company sites where the apparel associates worked (i.e.,

natural environment). The researcher traveled 6,000 miles to collect interview data. Interview times ranged from 45 minutes to one hour and 30 minutes. Tours of plants and interviews with plant personnel ranged from one to five hours. Table 2 itemizes the visitations to the sample site for Phase One data collection.

Each apparel associate interviewed was faxed or mailed an interview guide one day to one week before the interview. Each interview was conducted in person and audio-recorded. The researcher was flexible with company schedules and interview preferences. Some contact executive managers requested that the apparel associates were interviewed as a group, and other contact executives requested that the apparel associates were interviewed individually. Thus, Phase One interviews were conducted with an individual apparel associate or with groups of two to four apparel associates.

Table 2_

Phase One Apparel and Textile Visitations

Date(s)	Department Visited	Description
6/95	Merchandising	Textile fabric review
6/95	Merchandising	Sales, prototype communication
6/95	Manufacturing	Production process
6/95	Design Studio	Conceptual design
	Forecast Service	Conceptual design
6/95	Design Studio	Conceptual design
5/95	Knit Manufacturing	Prototype (sample) development
		Reviewed production techniques
5/95	Automated Shirt Manufacturing	Design for manufacturability
		Prototype (sample) development
5/95	Assembly	Reviewed production techniques
	Knitting	Reviewed production techniques

(table continues)

Date(s)	Department Visited	Description
5/95	Production	Coated textile finishing process
5/95	Textile Dyeing	Garment dyeing process
	Knitting Mechanics	Knitting stitch design setup
4/95	Pattern Making	Engineered stripes, CAD
4/95	Prototype Development	Department tour
4/95	Forecasting	Projected product quantities
4/95	Quality Control	Product quality issues
4/95	Design	Engineering design process
4/95	Textile printing	Production process
4/95	R & D	Color approval and product development
4/95	Textile knit printing	Production process
4/95	Purchasing	Vendor certification
3/95	Product development	Current process
3/95	Merchandising	Design concept meetings Merchandise Manager interview
3/95	Engineering	Costing
3/95	Knit manufacturing	Yarn dyeing & finishing
3/95	Woven production	Production process
3/95	Design studio	Textile design development, CAD
3/95	Sales	Sales meeting
3/95	Sales Converting	Sales meeting, fabric converting
3/95	Sales	Sales meeting
3/95	Technical services	Costing
3/95	Merchandising	Design process
3/95	Pattern making	Product development
3/95	CAD, Fabric services	Design presentation Purchasing
3/95	Product development	Overview, set up interviews
2/95	Merchandising, Forecasting	Design concept, sales Projections, Past sales review
2/95	Pattern making	CAD, current process
2/95	Design, Engineering	Fabric and garment review
2/95	Merchandising	Design concept meeting
2/95	Merchandising	Overview, set up interviews
1/95	Merchandising services	Overview, set up interviews
12/94	Production	Plant tour
10/94	Human resources Engineering	Research proposal meeting

Interview questions were focused on documenting the design and product development process. During Phase One interviewing, the researcher used Patton's (1980) general interview guide approach. The present study's interview guide was a list of questions and important issues prepared in advance of an interview (see Appendix D for sample company interview letter). The use of an interview guide helped the researcher by (a) serving as a guide and a checklist to ensure that relevant topics were addressed; (b) providing an avenue for replication of interview questions; (c) providing flexibility in the wording and sequence of questions; and (d) informing apparel associates of the interview topic prior to the appointment.

For the present study, the researcher focused on the decisions that apparel associates made during each functional design and product development activity. Decision questions were developed based on recommendations from Patton (1980), Wilcox (1972), and Malhotra (1993). The researcher assumed that decisions relayed by interviewees were (a) based on knowledge, (b) linked to commonalities with past decisions, (c) a network of relationships linking goals with consequences, and (d) explicit thoughts. Malhotra recommended that questions should focus on (a) events that led to a decision, (b) available courses of action, (c) criteria used to evaluate alternate courses of action, (d) information needed, and (e) the handling of information.

During data collection, the researcher discovered that apparel associates provided more useful answers on inputs, outputs, controls, and mechanisms by phrasing the questions with a decision focus (see Appendix D for sample company interview letter). In the present study, the researcher focused interview questions on: (a) functional activities within design and product development, (b) criticality of when particular information was needed, (c) individuals who made certain decisions, (d) what information an individual needed to make certain decisions, and (e) the sequence of activities. In addition, to get

information needed for the $IDEF_0$ diagram, the researcher asked apparel associates about functional job activities: what information was needed (inputs), what factors controlled activities (controls), the results of an activity (outputs), and how the activity was accomplished (mechanisms). Henceforth, inputs, controls, outputs, and mechanisms are referred to as ICOM.

Performance measurement information was gathered during the interviewing stage of Phase One. The researcher asked apparel associates about the performance of the current process. Example questions were, "When does the process go smoothly, when is the process out of control?" When is your process expensive"? "How would you describe the quality of line development?" Performance measurement questions were structured to identify the potential for process improvements for general categories (e.g., color development) of the *as is* environment. The researcher focused on time-to-market, cost, and quality information performance measurement questions (see Appendix D for sample company interview letter).

Observing the Subjects

In the present study, a triangulation method was used that combined observation with interviews. All of the apparel associates were interviewed in their natural work setting. During interviewing, the researcher observed and took field notes on daily activities, equipment, and facilities. In addition to interviewing, the researcher observed the apparel associates at company headquarters, textile supplier conference rooms, and manufacturing facilities. At company headquarters, the researcher observed apparel associates in work rooms and conference rooms during formal meetings, informal meetings, and planning meetings. In textile supplier conference rooms, the researcher observed fabric planning sessions. All of the apparel manufacturers and suppliers included in the sample invited the researcher to observe and tour plant manufacturing

facilities. The researcher observed the following facilities: knit manufacture, knit assembly, prototype assembly, flexible sewing unit, apparel assembly, automated component sewing, fabric engraving, knit screen printing, knit and woven fabric strike-off, textile print dyeing, textile piece good dyeing, textile garment dyeing, cutting departments, special operations departments, and distribution.

Data Analysis

Phase One results diagram the *as is* environment. The IDEF diagramming techniques were used. To achieve the results, the researcher combined data analysis procedures from Marca and McGowan (1988) and Tesch (1990). The researcher's $IDEF_0$ goals were to diagram the functional activities and related ICOM for the *as is* environment in preparation for the functional activities, and mechanisms in the *to be* environment.

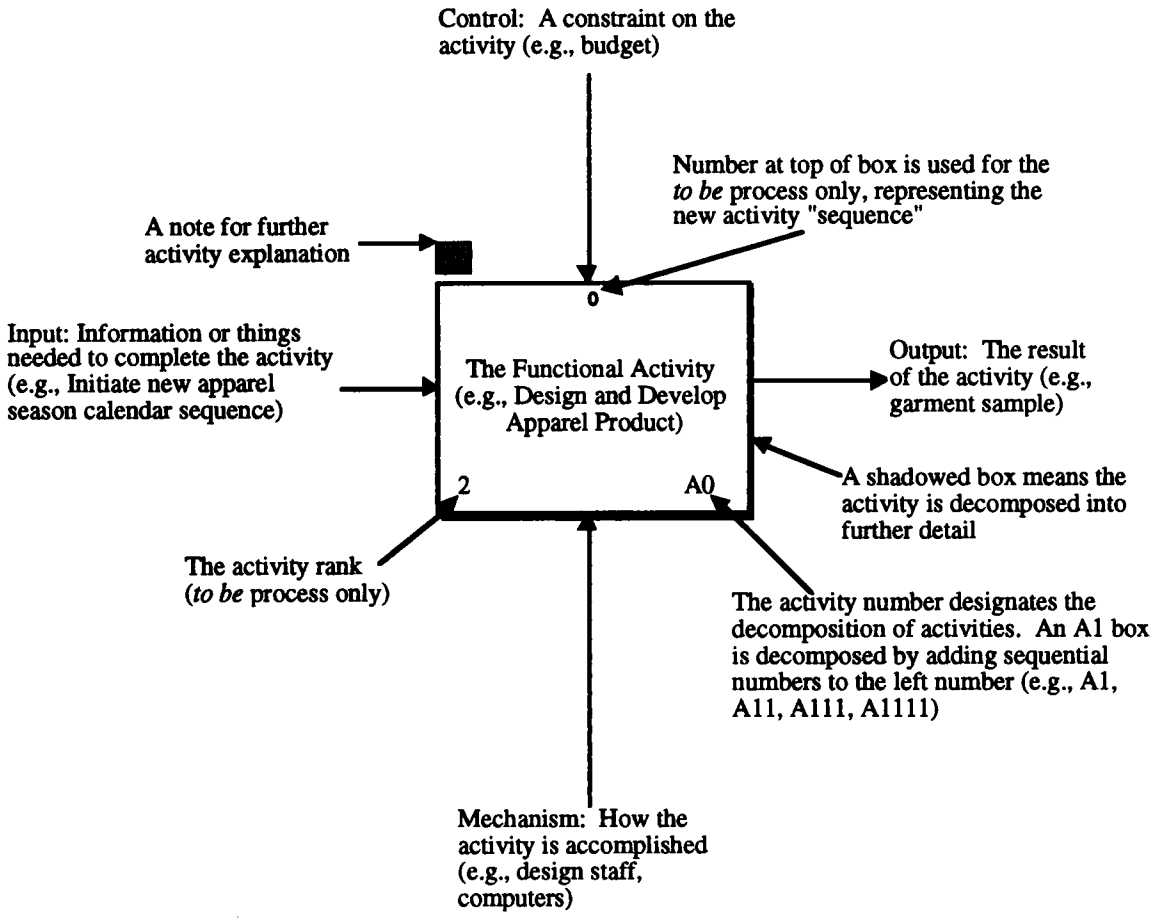
IDEF Explanation

The accepted analytical diagram for mapping decision making has been Integrated Computer-aided Manufacturing (ICAM) DEFinition or IDEF (U. Menon, personal communication, February 1995). The specific IDEF diagram type, appropriate to this study, is the $IDEF_0$ function activity diagram that illustrates a system's activities (Jayaraman, 1990). The researcher used $IDEF_0$ analytic graphic diagrams to illustrate a comprehensive *as is* environment and to create a CE apparel framework. Marca and McGowan (1988) stressed that models are developed with a specific purpose and viewpoint which influences how the researcher needs to collect data. A viewpoint is drawing a diagram from one perspective. The viewpoint for the present study was a Ph.D. student/analyst perspective and was based on interviews of representatives from actual firms. The purpose of Phase One $IDEF_0$ diagram results were to document the *as is* environment for use in identifying the sequential flow and process performance. The

purpose of Phase Two $IDEF_0$ diagrams was to create a *to be* environment using the CE approach.

$IDEF_0$ uses standard A-0 and A0 diagramming techniques (Marca & McGowan, 1988). The A-0 and A0 diagramming techniques have a standard format for diagram readability. An individual can read an IDEF diagram similar to reading a formal written outline. The A-0 diagram is the top diagram of a model and is a summary for all activities represented in the model. The A-0 diagram breaks down to lower hierarchical level diagrams. Each diagram has functional activities that are symbolized by a box. Functional activities represent what is accomplished by an organization or a process. Each functional activity has a hierarchy that breaks down to lower levels to show further activity detail. The amount of detail shown in an $IDEF_0$ diagram depends on the purpose of the model (Materials Laboratory, 1981).

Figure 13 shows the basic framework for an $IDEF_0$ diagram. The $IDEF_0$ diagram specifies data dependencies among activities. Data dependencies can be inputs needed, outputs created, or constraints required (CERC, 1992). The ICOM are written on the outside of a box and reading clockwise from left are inputs, controls, outputs, and mechanisms. Inputs are items that are needed to conduct a functional activity (e.g., supplies, instructions) and are written to the left of a functional activity box. Controls put constraints on activities (e.g., job completion requests, standards manual) and are drawn on top of a functional activity box. An output is data that is created (e.g., a part, job estimate cost) when a functional activity has been performed. An output is drawn to the right of a box. Mechanisms are the means by which a functional activity is accomplished (e.g., supervisor, computer database) and are drawn on the bottom of a functional activity box (Materials Laboratory, 1981).



Purpose: To document the current *as is* apparel design and product development process for use in identifying the sequential flow and process performance.

Viewpoint: Ph.D. student/analyst perspective based on interviews of representatives from actual firms.

NODE A0 ◄— Indicates where you are in the diagram.

Figure 13. Reading $IDEF_0$ diagrams.

Each functional activity is numbered with an Axxx (i.e., activity) number. The Axxx number represents the activities and ICOM. The sequential numbering of the Axxx number, along with arrows, shows how activities are constrained in a process (Materials Laboratory, 1981). For example, in Figure 14, functional activity A2 cannot be completed until the receipt of an output from functional activity A1.

The ICOM arrows can be split or joined in an IDEF diagram. A split arrow indicates that specific inputs which come from a general category are needed for two separate functional activities on the same diagram. A joined arrow is drawn when multiple outputs from two separate functional activities are combined to create an output (Materials Laboratory, 1981). An organization's performance can be diagrammed using control or output arrows to diagram process constraints and rework cycles. Rework cycles are drawn as backward loops: the output from one box is drawn so that it becomes an input for a previous activity. A reader who follows diagrammed rework cycles can identify activities that need improvement (see Figure 14).

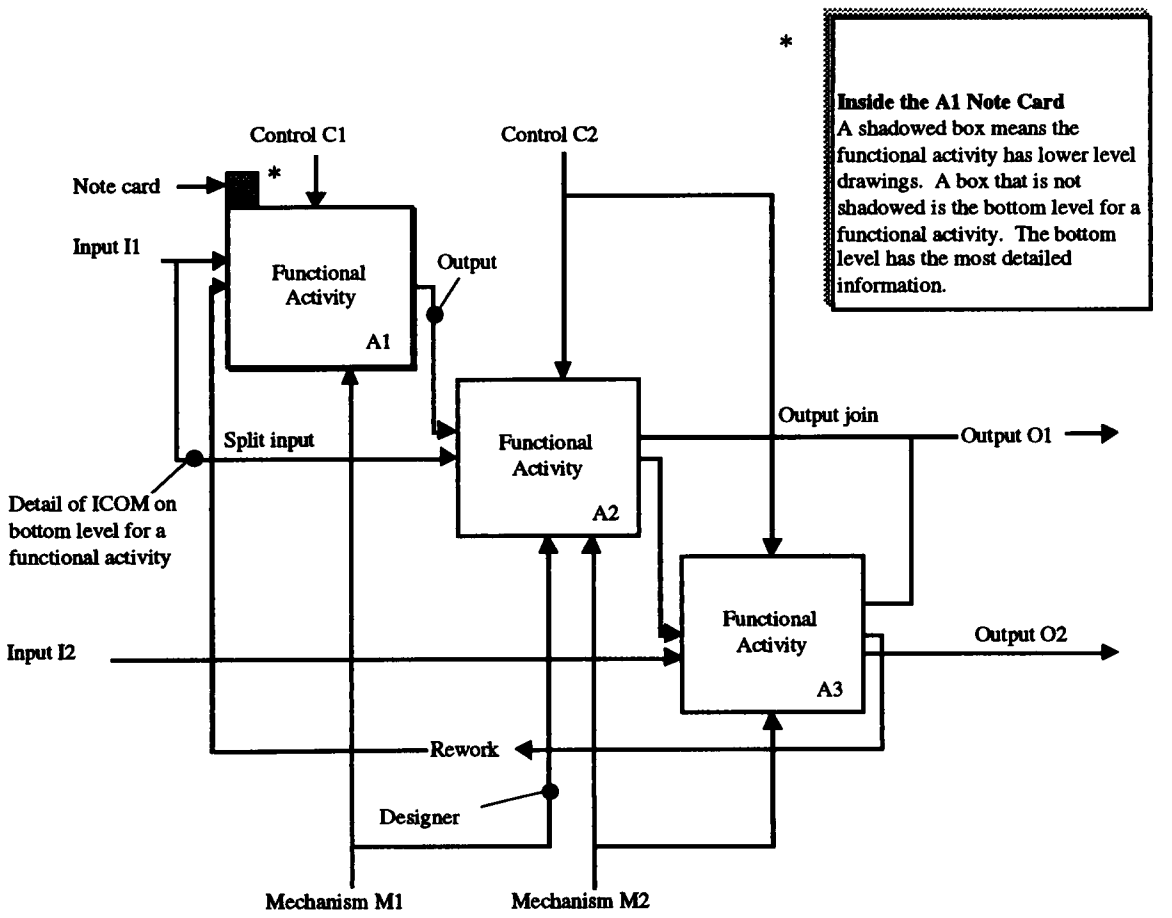


Figure 14. $IDEF_0$ Basic format (adapted from Marca & McGowan, 1988).

Authoring

Authoring is the process by which a researcher analyzes data, documents knowledge acquired during interviewing, and draws diagrams (Marca & McGowan, 1988). Marca and McGowan and Tesch (1990) described the same goals for the authoring phase: The researcher analyzes information collected during interviewing, then synthesizes the information and groups similar activities into a new understanding. Tesch provided more specific guidance for the authoring stage than Marca and McGowan. The data analysis procedure (i.e., authoring) outlined by Tesch is to (a) transcribe field notes and information, (b) segment data, (c) de-contextualize data, (d) code data, and (e) re-contextualize data. To develop the diagrams, the researcher used Tesch's data analysis procedure of de-contextualization and re-contextualization. The authoring stage of the present study specifically included (a) tape transcription, (b) de-contextualizing transcript data, (c) re-contextualizing transcript data into a manually produced $IDEF_0$ chart, and (d) further re-contextualizing data into computer drawn charts with the addition of comprehensive ICOM.

Transcribing tapes. During transcription, a researcher rewrites field notes or oral interviews into written documents and catalogs visual documents (Tesch, 1990). Tape transcription commenced April 1995 and was completed January 1996. The researcher used 90-minute, voice-only record tapes. Data collection generated a total of 57 tapes. Each tape was numbered sequentially, then labeled by company and by interview topics. Tape transcription took the researcher an average of 5 hours and 30 minutes per 45 minutes of tape. The tape transcription took a total of 627 transcription hours. The completed transcribed interviews were 770 typewritten pages.

De-contextualizing transcript data. Tesch (1990) described the first stage of de-contextualizing data as the process of creating data segments by separating relevant

portions of the transcribed data from its context. A data segment contains one idea and is a unit of text that makes sense by itself, even when it is out of context. The researcher read the transcripts and marked phrases in interview transcripts with a highlighter that identified a data segment for functional activities and ICOM. Each functional activity and ICOM were coded with different highlight colors: activities = blue, inputs = yellow, controls = green, outputs = pink, and mechanisms = purple.

The researcher continued de-contextualization by reviewing transcripts with the same topic across companies. For example, all of the transcripts on pattern making were read and analyzed. The goal at this stage was to identify consistency of data segments in interview transcripts. The researcher read transcripts and looked for consistency in phrases used, sequencing of steps, and ICOM. To maintain consistency, the researcher created a construct consistency table, and then read and interpreted the transcripts several times.

De-contextualizing functional activities. To increase the research construct validity, a construct consistency table was developed. During interviews and observations, the data collected from each company, and thus the data segments, were phrased in company-specific terms. Each company's functional activity was listed in a construct consistency table with the other companies' corresponding functional activity. When more than one company in the sample conducted the same activity but had different phrases, a generic construct phrase was created for use in the $IDEF_0$ charts. All of the functional activities, used by multiple companies, have generic construct phrases, and are represented in the $IDEF_0$ diagrams.

Due to the varying products made by each company, all activities were not performed by all companies. To create a comprehensive design and product development framework, all activities conducted by the sample were included in the $IDEF_0$ diagrams,

even if only one company completed an activity. The construct consistency table was used by the researcher for Phase One and Phase Two data re-contextualization.

Re-contextualizing the transcript data. The next stage of data analysis was to re-contextualize data. Consistent with Tesch's (1990) re-contextualization steps, the researcher identified, interpreted, and organized data patterns according to a theoretical or conceptual framework. For example, data segments on *create apparel line* were coded and grouped together. The conceptual framework that the researcher used to de-contextualize the interview transcripts was $IDEF_0$. The goal of this re-contextualization stage was to group concepts into logical categories and begin the creation of generic apparel design and product development diagrams.

To create the $IDEF_0$ charts, the researcher used Marca and McGowan's (1988) modeling procedure to re-contextualize transcript data into $IDEF_0$ charts. $IDEF_0$ chart development involved creating activity card templates, writing in ICOM and functional activities on activity cards, sorting the activity cards, and creating a series of posters with the cards. The researcher created activity card templates by drawing graphics using MacDraw® software (see Figure 15). The researcher wrote the functional activity generic construct phrases from the construct consistency table on each activity card template. To comply with IDEF rules, the generic construct phrases commonly used by the sample were changed to a verb phrase. The researcher wrote segmented ICOM data on the activity card templates.

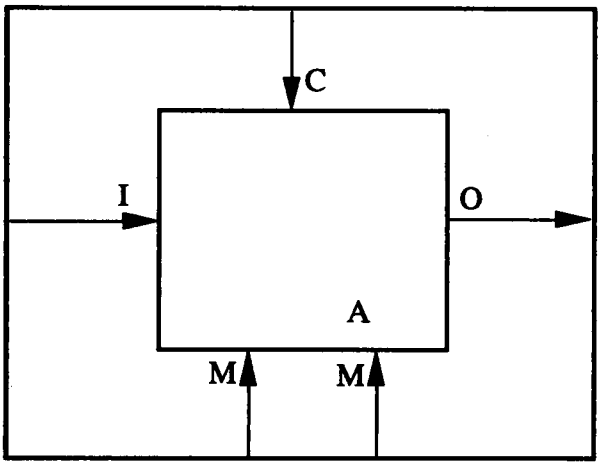


Figure 15. Activity card templates.

Using Strauss and Corbin's (1990) approach of allowing the data to emerge into categories, the researcher sorted the apparel design and product development process cards into logical groups. The cards were manually organized and reorganized to create logical sequencing of functional activities in the design and product development processes. The researcher determined that the design and product development categories were (a) create apparel line, (b) develop prints and colors, (c) implement fabric design and special operations, (d) create garment pattern and prototype, (e) set production specifications, and (f) produce samples.

$IDEF_0$ is a hierarchical constraint diagram; therefore, the next stage was to sort the activity cards according to hierarchy, sequence, and constraints. The researcher used the line development calendar as a guide to initially determine the activity sequence in the *as is* environment. The apparel design and product development time started with a seasonal line conception and completed with sales samples production. Consistent with Glock and Kunz's (1990) information, the apparel associates tracked product development time-to-market by using a line development calendar. Through integration with the apparel associates, the researcher was able to follow one complete design and product development cycle from start to finish.

Through the data collection process, the researcher found that quantitative measures for cost and process quality were not used by the sample for the design and product development process. Process quality and cost analysis in the present study were restricted to implied increased cost and implied decreased process quality as documented by the subjects. During data collection the researcher discovered that implied increased cost and decreased process quality were due to rework activities, nonvalue-added activities, and process delays. To evaluate process performance for the *to be* environment, the researcher used a qualitative approach. Subjects were asked to evaluate whether the CE apparel model potentially could improve performance for time-to-market, cost, and process quality.

The researcher analyzed the transcripts and discovered that activities in a process (e.g., color development) were controlled by constraints. The researcher also grouped the activity cards according to constrained decisions that controlled commencement time of a group of activities. For example, color development did not start until receipt of a color standard that was determined during the create apparel line stage. Therefore, all activities leading to the submitting of a color standard to the textile vendor were sequentially ordered earlier in the process.

The researcher created large posters for each design and product development category (e.g., create apparel line). The activity cards were glued and mounted on the posters. Several rounds of re-contextualizing (i.e., reorganizing the activity cards) were necessary to create an accurately mapped representation of the current process. The researcher continually referred to the transcripts to make sure that the mapped $IDEF_0$ process represented an across company perspective. The line development calendars represented design and merchandising activities and was used as a validity check for such activities. Some product development activities (e.g., conduct engineering process) were

not on the company's product development calendars. During data collection, apparel associates had described design and product development activities that were not represented on the product development calendar. The researcher relied on cross-referenced transcripts to include all design and product development activities in the IDEF posters.

Accompanying the $IDEF_0$ charts, the IDEF method requires the creation of an A0 Node index. The A0 Node index is a hierarchical outline of the functional activities represented in the $IDEF_0$ charts (see Appendix C for A0 Node index). Technical review experts (e.g., Ph.D. committee members) reviewed the A0 Node index and $IDEF_0$ posters.

Further Re-Contextualizing Data into Computer Drawn Charts

The researcher entered the re-contextualized data from the posters into computer drawn $IDEF_0$ charts. The Topdown Flowcharter® software program was used to draw the $IDEF_0$ charts. The researcher did further re-contextualizing as data were entered. First, the researcher drew the functional activities and ICOM. The researcher then referred to the transcripts to add more comprehensive ICOM information to the diagrams. The researcher drew 120 diagrams with 434 functional activities. The design and product development activities completed by the apparel associates represented internal and external organizational activities. The sequence of the functional activities demonstrated the constraints on activities in the process. For example, develop colors and prints (A2) is constrained by needing inputs from create apparel line (A1).

IDEF is a hierarchical diagramming structure in which a general process such as design and product development is decomposed into greater detail. To represent the *as is* environment, each category (e.g., create apparel line) was decomposed to a minimum of three levels and a maximum of five levels. The information obtained in Phase One on

ICOM was later used for further re-contextualization in creating the CE apparel framework in Phase Two.

Distributing

Marca and McGowan (1988) outlined distribution as creating a kit of diagrams for reader review. The readers for the present study were the apparel associates who were interviewed. A kit consisted of a small portion (i.e., no more than 20 pages) of drawn diagrams (i.e., $IDEF_0$ diagrams). Kits could either be mailed to reviewers or could be administered in person (Marca and McGowan). Being empathetic to the apparel associates' schedules, the researcher determined that it was more efficient to have the kits reviewed in person during set appointments. The kits consisted of a cover sheet on reading $IDEF_0$ diagrams and a small section of the design and product development process. The validated kits were used to revise the $IDEF_0$ diagrams.

Validating

After the kits were distributed, they were validated by apparel associates. For this research, respondent validation was adapted from Marca and McGowan (1988) and Silverman (1993). Respondent validation was used to increase research validity for each $IDEF_0$ kit. A kit review is consistent with Silverman's description of respondent validation. Respondent validation is when an interviewee reads, clarifies, and corrects transcribed interview information. The purpose of critiques was to attain accurate information from individuals who actively work within the *as is* environment. Marca and McGowan noted that IDEF diagrams are valid if they represent a process and are usable for their intended purpose.

The researcher contacted the contact management executive to arrange appointments for kit review meetings. The contact management executive also set up appointments for kit validation. The kits were hand-delivered to apparel associates and

they validated the $IDEF_0$ kits in person March-April 1996. The apparel associates validated a small section of the *as is* environment within a one hour meeting time. The researcher gave oral instructions to each apparel associate on how to read $IDEF_0$ diagrams and how to review each of the diagrams (see Figure 13). The researcher orally gave validation instructions to the apparel associates. The apparel associates were given instructions to (a) review the functional activities' constraining factors to determine if they were drawn in the correct sequence, (b) redraw the correct sequence of functional activities if necessary, (c) add any missing ICOM information, (d) delete any irrelevant ICOM information, and (e) add any missing functional activities.

Apparel associates were allowed to ask questions during the validation meetings. During the validation meetings, 37 apparel associates validated that the $IDEF_0$ models were correct as drawn or with revisions (see Table 3). The apparel associates reviewed and wrote corrections on the $IDEF_0$ drawings by either changing the sequence of functional activities, adding ICOM information, or deleting ICOM information.

Table 3

Subjects Validating Phase One $IDEF_0$ Diagrams

Subject	Total N=
Apparel Designer	4
CAD Artist–Apparel	1
Cost Engineer	1
Director, Merchandise Services	1
Division Engineer/Director of Engineering	2
Forecast Associate	2
General Merchandise Manager	3
Knitting Manager	1
Marking Supervisor	2
Merchandise Associate	2
Pattern Maker	3
Fabric Buyer	2
Product Engineer	2

(table continues)

Subject	Total N=
Production Line Supervisor	1
Prototype Supervisor	1
Quality Control–Piece Goods and Garment	2
Research and Development Manager	1
Sample Issue Coordinator	1
Specification Writer	2
Textile Colorist	1
Vice President, Manufacturing	1
Vice President, Product Line	1
Total	37

Revising $IDEF_0$ Diagrams

The researcher used Marca and McGowan's (1988) recommendations to react to and consolidate from reader comments. The researcher reviewed the apparel associates' critiques, corrections, and improvements on the $IDEF_0$ diagrams. The researcher responded to diagram critiques by consolidating reader critiques, correcting the functional activity phrases, reordering sequences, adding omitted ICOM information, and deleting irrelevant ICOM information. The researcher telephoned a kit reviewer if a diagram validation needed clarification.

Gaining Approval

Marca and McGowan (1988) recommended that IDEF models needed review by a technical review committee. Approval was gained through technical reviewers (i.e., Ph.D. committee members). The gain approval stage involved diagram review, $IDEF_0$ drawing revision, and gaining approval for revised drawings. The primary goal of this stage was to demonstrate that the diagrams thoroughly documented the *as is* environment. The committee members recommended diagram editing changes and phrase consistency among hierarchical levels. The outcome of Phase One provided a documentation of the *as is* environment. The functional activities and ICOM used in Phase One became a baseline

for re-contextualizing data in Phase Two into a *to be* model. The Phase One model was completed before Phase Two re-contextualization commenced.

Phase Two: Apparel Concurrent Engineering Framework

The researcher's goal for Phase Two was to develop a CE framework (e.g., *to be* environment) that integrated apparel design with product development. The underlying premise of creating a *to be* environment was that the *as is* environment functional and sequential activities could be reorganized according to CE goals. Primary CE goals are for the design team to consider a product's quality, cost, life cycle, manufacturing schedule, and user requirements early in the design phase (Carver & Bloom, 1991). The CE design team uses CE conceptual statements in order to accomplish CE goals (e.g., Design for Quality) that act as constraints during the design phase.

Data Collection

Data collection for Phase Two consisted of using open-ended questions and structured questionnaires in a focus group environment to create the integrated apparel design process. The sample population for Phase Two were apparel associates that had been interviewed during Phase One (see Table 1).

Preparation for Data Collection

A review of CE literature and analytical models was used for data collection and data analysis. Reviewed literature by the researcher was the basis for creating interview questions and developing questionnaires. The researcher's review of published CE models was used to create a preliminary CE apparel framework. CE conceptual statements were derived from a synthesis of CE literature.

Structured Interviews

The interview process as adapted from Tesch (1990) and Marca and McGowan (1988) was initially tried for Phase Two. The researcher wrote structured interview

questions on CE conceptual statements of design for manufacturability, cost, assembly, and quality. Patton (1980) noted that a benefit of structured questioning in qualitative research is reduced interview bias from individual differences, circumstances, and variation in questioning. Using Patton's approach, open-ended questions were written and given to apparel associates; however, this approach was not effective and was replaced with survey methods.

A preliminary set of interviews from March 1995 to May 1995 established that the associates' answers to the open-ended questions did not provide enough information on how specific apparel functional activities could be reorganized to create a CE apparel model. For example, one answer provided by multiple apparel associates was "better communication." While better communication is a documented success factor of CE implementation, the apparel associates did not address how communication could be improved. However, the apparel associates did provide useful information for evaluating the current process performance which was incorporated into the evaluation of the *as is* and *to be* environments. The researcher felt that interviews for projecting a new process were not effective, because the majority of subjects were (a) not management but were day-to-day operational workers, (b) not used to making future-oriented strategic decisions, and (c) restricted in thinking by current paradigms. Thus, a more structured approach was adopted to create the CE apparel model.

Development of Survey Instruments

The researcher felt the apparel associates needed more guidance in creating the CE apparel framework even though Patton (1980) noted that structured questioning in qualitative research reduces flexibility and does not allow the researcher to pursue unanticipated topics. The questionnaires were developed to (a) identify applicable CE apparel conceptual statements, (b) develop a preliminary CE framework, (c) create a Q-Sort that reorganized apparel activities into a CE framework, (d) identify multi-

disciplinary apparel and textile teams, and (e) identify enabling technology applicable for design and product development.

Identification of applicable CE apparel conceptual and operational statements. A review of CE literature and analytical models was the basis for creating a preliminary CE framework and developing questionnaires. The common published CE conceptual statements were to design for manufacturability, cost, quality, life cycle-inspectability, life cycle-reliability, life cycle-maintainability, and enabling technology (Crow, 1992; Hyeon et al., 1993; Schmitz & Desa, 1992; Sharon, 1992; Turino, 1992) (see Chapter II). To add breadth to the CE conceptual statements, the researcher reviewed published literature and developed each CE conceptual statement (e.g., design for manufacturability) and included operational statements (Crow; Hyeon et al.; Schmitz & Desa; Sharon; Turino). The conceptual and related operational statements were written on a questionnaire (see Appendix D for CE design for manufacturability, quality, cost, enabling technology and life cycle questionnaire). Carter and Stilwell-Baker (1992) indicated that CE implementation needs a starting point in order to improve the product design process. As a company implements CE, the process continually improves. Following Carter and Stilwell-Baker's ideas, the questionnaire was designed to have apparel associates indicate whether a CE operational statement was currently used in the *as is* environment. The apparel associates selected a discrete answer from the following (a) yes, we use all of the time; (b) no, wish we used; (c) no, not applicable to apparel; or (d) do not know (see Appendix D).

The researcher used the questionnaire results to create a preliminary CE apparel framework. The researcher used CE conceptual statements from published CE literature (see Chapter II) to develop a preliminary CE apparel framework. The researcher used questionnaire results to identify the CE operational statements that would be used in the framework. The CE apparel conceptual statements that apparel associates selected as

using either all of the time or some of the time became the CE apparel framework operational statements. Regan and Kincade's (1996) article "Interpretive Examination of Concurrent Engineering Constructs for Apparel Manufacture" details the questionnaire results (see Appendix A for published dissertation abstract and article).

Creation of Q-Sort instrument. A Q-Sort is a comparative scaling technique that allows a researcher to categorize a large number of objects. The researcher sorts and groups Q-Sort objects based on their similarity with preset research criteria (Malhotra, 1993). In the present study, the researcher's goal of Q-Sorting functional *as is* activities was to break down a paradigm of "this activity has always been done this way." The Q-Sort instrument was designed to determine how the sample would match apparel functional activities with CE conceptual and operational statements. The segmented data from transcripts that were generated during Phase One re-contextualization were used to create the Q-Sort activity cards. The functional activities that the researcher had marked with a highlighter from transcripts were typed on the Q-Sort activity cards. The researcher typed the segmented data that were company-specific to enhance apparel associate understanding of the functional activities. De-contextualized data were apparel design and product development functional activities and inputs that were listed in the table of constructs created during Phase One. The Q-Sort activity cards were drawn using the MacDraw® software program. Activity card phrases and number of cards (N = 140-160) ranged by company depending on the product that the company produced. The activity cards were cut into 2″X 3″ cards, bundled, and placed in a manila envelope.

During Q-Sort instrument development, the researcher referred to the construct consistency table that was created during Phase One. The construct consistency table was useful for Q-Sort instrument development as a double check by the researcher to ensure that each company had common activities. For example, if the strategic business unit

meeting and concept meeting represented the same activity in the construct consistency table, the researcher gave the sample an activity card with the phrase that the company specifically used.

Creation of design for enabling technology instrument. The goal of design for enabling technology is to share knowledge (Carver & Bloom, 1991). The questionnaire was designed to elicit the opinions on how knowledge would best be shared in a CE environment. The enabling technology questionnaire was designed as a checklist that cross-referenced functional activities with specific types of enabling technology (see Appendix D for enabling technology questionnaire). The functional activities were the same phrases used in the Q-Sort instrument. The researcher read interview transcripts and listed enabling technology (e.g., CD-ROM) that was used by at least one subject in the sample to identify current enabling technology used. In addition, the researcher read apparel equipment advertisements to acquire ideas to add to the enabling technology list.

Development of multi-disciplinary apparel and textile team instrument. As CE is a team approach, the CE apparel framework was not complete without the addition of multi-disciplinary teams. The researcher developed a multi-disciplinary team checklist questionnaire to help associates break down paradigms that a particular person must always be responsible for certain activities. Members of a multi-disciplinary team were defined as any team member inside or outside a firm. The questionnaire was written with the functional activity phrases used in the Q-Sort instrument. The activities were cross-referenced with potential multi-disciplinary team members (see Appendix D for design for manufacturability multi-disciplinary team questionnaire). To determine potential multi-disciplinary team members, the researcher read the transcripts from Phase One and listed the sample's apparel positions. The apparel positions were written on the questionnaire as potential team members.

Administration of Questionnaires

Phase Two data collection used a focus group approach in which questionnaires were given to apparel associates. The researcher administered questionnaires to the focus group in person, except for a few apparel associates who received mailed questionnaires. The apparel associates who were mailed a questionnaire were not able to participate in person. This was due to their unavailability when the questionnaire was administered or because, of the apparel associate's physical location of employment. Krueger (1988) defined a focus group interview as a researcher interviewing specific individuals in a small group. Individuals were specifically selected for the focus groups, because they had certain characteristics relevant to the study. CE was a new concept to the apparel associates, and they benefited by having focus groups to clarify new terminology. The apparel associates helped each other understand the CE approach, respond to new ideas, form ideas for comments, and provide insights on how other people perceived specific enabling technology or multi-disciplinary team use. Krueger noted that using focus groups for data collection allows the researcher to categorize and quantify data. In the present study, the researcher benefited from giving questionnaires to focus groups during data analysis by being able to use descriptive statistics to quantify Q-Sort data.

The researcher contacted the contact management executive and requested that apparel associates who represented selected functional areas participate in the focus groups. The apparel associates requested were contacted and selected by the contact executive manager to participate in the focus groups.

The questionnaires were administered to the focus groups September 1995 through November 1995. Interviews were conducted at the apparel associates' company sites in conference rooms. Interview time ranged from 45 minutes to one hour and 30 minutes. Table 4 lists the contacts with the sample for Phase Two data collection and data validation.

Table 4

Phase Two Apparel and Textile Contacts

Date(s)	Apparel Associates Interviewed	Description
9/96	Quality Control Supervisor Engineers	Phase Two interview with plant personnel
10/95	Merchandisers, Designers, Engineers, Fabric Buyer, Pattern Maker, Plant Manager, Prototype Supervisor	Phase Two research interviews
10/95	Designers Textile Representative	Phase Two research interviews
10/95	Merchandiser, Quality Specialist, R & D staff	Phase Two research interviews
11/95	Pattern Maker, CAD Artist, Quality Control Manager, VP Product Line, Merchandiser, Merchandise Services	Phase Two research interviews
11/95	VP Product Line, Merchandisers, Designers, Forecaster, Specification Writer, Merchandise Services, Division Engineer	Phase Two research interviews
11/95	Pattern Maker, Specification Writer, VP Engineering, Prototype Supervisor	Phase Two research interviews
11/95	Plant Manager, R & D staff, Colorist, Assembly Supervisor, Inventory Planning Specialist	Phase Two research interviews
3/96	Merchandise Associates, Engineers, Fabric Buyer, Pattern Makers, Marker Supervisor, Prototype Supervisor	Current process results review – $IDEF_0$ chart validation
3/96	Merchandisers, Designers, Engineers	$IDEF_0$ chart validation
3/96	VP Product Line, Fabric Buyer, Assistant Merchandiser	$IDEF_0$ chart validation
3/96	Pattern Maker, Specification Writer, Forecaster, Sample Coordinator, VP Engineering, Merchandise Services	$IDEF_0$ chart validation
4/96	VP Engineering, Merchandise Services, VP Product Line	CE– $IDEF_0$ diagram refinement
4/96	Designers, Merchandisers, Operations, Engineering	CE– $IDEF_0$ diagram refinement and validation
4/96	Colorist, Knitting Supervisor, Assembly Supervisor, Plant Manager, R & D Manager	CE– $IDEF_0$ diagram refinement and validation

CE apparel conceptual and operational statements questionnaire. The CE apparel conceptual and operational statements questionnaire was given to apparel associate focus groups. The questionnaire was given to a apparel associate focus group that represented a cross section of apparel product development functional areas. The functional areas represented were merchandising, engineering, management, manufacturing, merchandise services, and research and development (N=23). The researcher gave oral instructions for the apparel associates to mark the current use of specific CE operational statements in the *as is* environment.

Q-Sort. The Q-Sort was administered in person to small groups from October to November 1995. Thirty-three apparel associates participated in the Q-Sort. The apparel associates who participated represented all functional areas in the sample. Each apparel associate received a manila envelope with cards describing the CE conceptual statements and apparel functional activity cards. The researcher orally defined the CE approach and CE conceptual statements. The researcher orally explained that the activity card phrases were derived from the interview transcripts for their *as is* environment (i.e., Phase One). The researcher instructed the apparel associates to place the CE conceptual statement cards on the table in front of them. Using their industry experience, the apparel associates were instructed to sort the apparel functional activities under which they felt was the most appropriate CE conceptual statement of design for manufacturability, quality, cost, life cycle-inspectability, life cycle-reliability, life cycle-maintainability, or enabling technology.

Figure 16 shows an example of one CE conceptual statement card and one activity card given to the apparel associates. The apparel associates were asked to write a 1, 2, or 3 rank value on the blank line at the top right corner of the activity card. The rank number

indicated where apparel associates felt the activity should be placed within each CE conceptual statement (e.g., design for life cycle-reliability): early = 1, middle = 2, and late = 3. The Q-Sort took apparel associates an average of one hour and 30 minutes to complete. The researcher labeled the envelopes with the company code and the date the Q-Sort was administered.

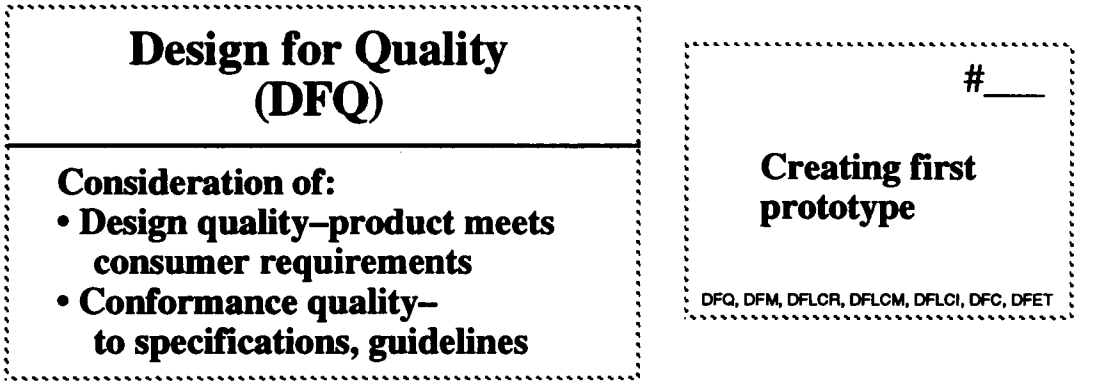


Figure 16. Q-Sort concurrent engineering operational statement and activity card example.

Design for enabling technology questionnaire. The researcher administered the enabling technology questionnaire in person to ten apparel associates. Two additional apparel associates were mailed the same questionnaire. These two apparel associates sent a facsimile of the questionnaire back to the researcher (N= 12). The focus group had a cross section of apparel product development associates. Functional areas represented were design, engineering, manufacturing, prototyping, merchandise services, pattern making, quality assurance, research and development, and textiles. The researcher orally instructed the apparel associates to mark the enabling technology for each functional activity listed, indicating how they would best like to receive the information. The questionnaire took the apparel associates 45 minutes to complete.

Multi-disciplinary apparel and textile team questionnaire. The researcher gave ten apparel associates the multi-disciplinary apparel and textile team questionnaire in person. Two additional apparel associates were mailed the same questionnaire. These two apparel

associates sent a facsimile of the questionnaire back to the researcher (N= 12). The focus group had a cross section of apparel product development associates. Apparel associates represented the functional areas of design, engineering, merchandise services, manufacturing, pattern making, quality assurance, researcher and development, and textiles. The researcher gave an oral explanation of multi-disciplinary teams, noting specifically that if product development members were not in the same physical location, virtual teaming allowed people to work together through integrated computer systems. For each apparel functional activity, apparel associates were instructed to mark team member(s) with an R who should be responsible, with an I for those who should provide input, and with an N for those who should be notified. The questionnaire took apparel associates one hour 15 minutes to complete.

Data Analysis

Phase Two data analysis consisted of developing the CE apparel framework. To develop the diagrams, the researcher used Marca and McGowan's (1988) modeling procedure and Tesch's (1990) ideas to de-contextualize and re-contextualize the data. To create the CE apparel framework, the researcher used descriptive statistics to de-contextualize the Q-Sort and questionnaires. The researcher refined the re-contextualized data on the *to be* $IDEF_0$ charts by using heuristics. The re-contextualized $IDEF_0$ *to be* model was validated by a focus group of apparel associates.

Authoring

The CE apparel framework development consisted of several phases. The first phase was to use descriptive statistics to de-contextualize (a) Q-sort activities, (b) the CE conceptual and operational statements questionnaire, (c) the multi-disciplinary team questionnaire, and (d) the enabling technology questionnaire. The second phase was to

re-contextualize data into manually drawn $IDEF_0$ posters. The third phase was to de-contextualize data into a computer drawn $IDEF_0$ model.

De-contextualizing Q-sort activities. The researcher created spreadsheet templates using Microsoft Excel® software. A separate spreadsheet was set up for each CE conceptual statement: design for manufacturability, quality, cost, life cycle-inspectability, life cycle-reliability, life cycle-maintainability, and enabling technology. The researcher referred to the construct consistency table created in Phase One to create a generic functional activity phrase list for each CE conceptual statement. The generic terms from the construct consistency table were the phrases used in the CE $IDEF_0$ functional activities. The use of consistent conceptual statements across companies increased the research construct reliability. Each apparel associate's categorical placement and rank for functional activities for a specific CE conceptual statement was recorded on separate spreadsheets. The researcher designed the spreadsheet to sum categorical placements, calculate a percentage, calculate an average rank for each company, and provide an overall total.

The researcher used descriptive statistics to analyze the Q-Sort activities. The researcher analyzed the following for each functional activity: (a) total frequency by company, (b) total percentage by company, (c) average rank by company, and (d) total percentage for all companies combined. Each of the 160 functional activities had a percentage calculation and an average rank for each CE conceptual statement (e.g., design for cost).

De-contextualizing the enabling technology and multi-disciplinary team questionnaires. The frequency of apparel associates' responses were totaled for the enabling technology questionnaire. The researcher also recorded apparel associates' frequency responses for the multi-disciplinary team questionnaire. For an apparel

associate's position to be accepted as part of the multi-disciplinary team for a specific functional activity, an acceptance rate was set at 30% or more of the total responses.

For the enabling technology questionnaire, an acceptance rate was set at 30% or more of total responses. If apparel associates selected a functional activity for a specific enabling technology type for 30% or more of the total responses, it was accepted for use in the *to be* environment $IDEF_0$ model. Many of the enabling technology responses did not meet the 30% acceptance rate; therefore, the enabling technology categories were collapsed into five general categories (see Appendix D, Table D-1 for collapsed enabling technology categories).

Re-contextualizing Q-Sort activities. As each apparel associate could place a functional activity in one of seven categories, there was a large range of possible answers (33 apparel associates X 7 categories = 231 possible responses). Because there was a large range of possible answers, the researcher and a committee member determined that an acceptance cutoff was 30% or more of total responses by two out of the three companies. A two-thirds majority by company was desired to achieve a higher consistency across companies in the sample. Each functional activity that met the cutoff acceptance rate was placed into the appropriate CE conceptual statement category (e.g., design for cost). If a functional activity met the acceptance cutoff for more than one CE conceptual statement, it was placed in multiple categories (e.g., design for cost and design for quality). The researcher sorted the activity cards that were used in the *as is* environment into a stack for each of the CE conceptual statements for each functional activity that met the acceptance cutoff for a CE conceptual statement.

Re-contextualizing Q-Sort activities by CE operational statements. Re-contextualizing the Q-Sort activities was the second phase in creating the CE apparel framework. An IDEF requirement to represent a process in a hierarchy was followed by

the researcher. The researcher's intent was to re-contextualize Q-Sort data to create a CE apparel model that had varying levels of CE abstraction: conceptual and operational. Concrete apparel functional activities were added to the diagrams. Developing a CE model with this approach would convey to apparel manufacturers a complete perspective of a CE apparel system. To create the final CE apparel model, concrete apparel functional activities were matched with the CE conceptual and operational statements. To accomplish the CE abstraction levels, the researcher (a) began creation of CE $IDEF_0$ posters, (b) identified CE operational statements for use in the charts, and (c) added concrete functional apparel activities.

Creating CE $IDEF_0$ posters. The researcher used IDEF diagramming techniques as described in Phase One to develop the CE apparel framework necessary to begin creating manually produced $IDEF_0$ diagrams. The researcher created a separate poster for each CE conceptual statement: design for manufacturability, quality, cost, life cycle-inspectability, life cycle-reliability, life cycle-maintainability, and enabling technology. The CE conceptual statements were the first hierarchical level represented in the A0 $IDEF_0$ diagram. The use of conceptual statements to represent CE analytical diagrams is consistent with the reviewed published CE analytical models (Crow, 1992; Hyeon et al., 1993; Schmitz & Desa, 1992; Sharon, 1992; Turino, 1992).

Identifying CE operational statements. By breaking down apparel paradigms, the Q-Sort results are designed to show break-through process design, a CE goal. Apparel associates sorted apparel activities into a CE framework based on the conceptual statements of DFQ, DFET, DFM, DFLC-I, DFLC-R, DFLC-M, and DFC. The next developmental stage of $IDEF_0$ diagrams was the identification of operational statements that were selected in the Q-Sort by apparel associates for each CE conceptual statement. For each conceptual statement (e.g., design for manufacturability), a percentage

calculation was completed for each associated operational statement (e.g., manufacturability considered at the start). An operational statement that had a 50% or more combined use in the *as is* environment either all of the time or some of the time was accepted for the CE apparel model (see Appendix A for dissertation articles). For each CE conceptual statement, the appropriate CE operational statements (e.g., manufacturability considered at the start) were placed across the top of each poster. The accepted operational statements became the second hierarchical level in the CE apparel $IDEF_0$ diagrams. Using IDEF hierarchical structure, each conceptual statement (e.g., DFQ) is broken down into lower level diagrams that represent CE operational statements and specific apparel activities. The lowest levels of hierarchical diagrams are the apparel activities within the CE operational statements.

Re-contextualizing the concrete functional apparel activities on $IDEF_0$ posters. The researcher placed a stack of functional activity cards on each poster. Consistent with Tesch (1990), the next stage was to re-contextualize the activity cards so that they were organized in a new context. The researcher used heuristics to blend CE with apparel and to categorize the accepted Q-Sort activities into a CE operational statement category. The functional activities were organized into logical groupings. Working within each of the logical groupings, the researcher organized the functional activities for concurrency. Consistent with CE goals, the functional activities were not organized according to the sequential order as diagrammed in the *as is* environment. Rather, the researcher used each functional activity ranking average across companies (*early* = 1, *middle* = 2, *late* = 3). The activities ranked as *early* were placed towards the top of the diagram. The activities ranked as *late* were placed at the bottom. Technical experts (e.g., Ph.D. committee members) reviewed the manually arranged CE $IDEF_0$ charts. The functional activities were reviewed and re-contextualized as needed to refine the logical sequencing of

functional activities and to confirm that the functional activities matched the operational statements. The functional activity cards were glued on the posters.

Multi-disciplinary teams and enabling technology. The researcher de-contextualized the data from the posters to create computer drawn $IDEF_0$ charts. The Topdown Flowcharter© software program was used to create the CE $IDEF_0$ charts. The researcher drew two $IDEF_0$ hierarchical levels showing the CE conceptual statements and operational statements. The researcher then re-contextualized the results of the multi-disciplinary team and the enabling technology questionnaires. The team members selected by the apparel associates were drawn on the charts. The team information was used for evaluating the *as is* and *to be* environments.

Distributing

The distribution process was adapted from Marca and McGowan's (1988) kit and review procedures described in Phase One. The kits consisted of manually created $IDEF_0$ posters for apparel associates' review. The researcher showed the $IDEF_0$ posters to the apparel associates in person. The review meetings lasted two hours.

Validating

The research project concluded with CE model validation by apparel associates. The purpose of validating is to receive accurate information from individuals who will ultimately use the system (Marca & McGowan, 1988). The researcher divided the validation responsibilities among the sample because CE model development required several stages of refinement and apparel associate availability was limited to two hours. In March and April 1996, varying stages of the CE apparel model were shown to and evaluated by apparel associates in the sample (see Table 4). Evaluating across groups increased the CE apparel framework's construct reliability and applicability to multiple apparel companies.

The researcher called contact management executives to arrange CE validation focus group meetings. A focus group participated in the first model validation. The apparel associates involved represented management, manufacture, and merchandise services (N=4). The researcher requested a focus group of merchandise managers, engineers, and management (N=7) for two companies in the sample. These apparel associates were desired because (a) they were involved with strategic planning and (b) the individuals had a holistic understanding of the design and product development process.

Validating the first CE model. The researcher created checklists with the CE conceptual statements, operational statements, and functional activities. The purpose of the checklists was for the apparel associates to validate the heuristics used by the researcher. The researcher felt that checklists were an efficient method for apparel associates to validate functional activity organization. The researcher instructed the apparel associates to check the best operational statement category for the functional activities listed. The participants used their job expertise to evaluate the CE apparel model and to indicate whether they would approve, reject, or revise represented sections of the detailed model.

Validating the second CE model. A focus group of managers was asked to validate the CE re-contextualized model during a second model validation. Since CE apparel implementation was beyond the scope of this research, the apparel associates were asked to project the use of the CE apparel model in the future. During the focus group discussion, the participants were asked open-ended questions and had directed discussion about the specific components of the CE apparel model. The information provided by the apparel associates during the focus group was recorded using field notes. The researcher instructed the focus group to walk over to and read apparel functional activities for each CE conceptual statement poster. The apparel associates were instructed to either reorganize activities or approve the represented functional activity organization

for each CE operational statement. As the Q-sort de-contextualization for functional activities had an across company construct reliability, the apparel associates were instructed not to move functional activities to a different CE conceptual statement poster. The researcher used results of the validation meeting to correct and improve the CE apparel framework.

Evaluating the *To Be* Environment

The same apparel associates who participated in the CE framework validation meetings participated in a focus group that evaluated the *to be* environment. The apparel associates were asked to respond to open-ended questions on potential process improvement. The researcher instructed the apparel associates to answer the open-ended questions based on their judgment and industry experience with the current process. The researcher gave apparel associates a kit with structured, open-ended questions and computer drawn $IDEF_0$ diagrams with multi-disciplinary team identification. The apparel associates were asked to refer to the functional activities that were on the CE $IDEF_0$ posters.

Each apparel associate answered questions comparing the activity sequence in the *as is* environment with the activity rearrangement in the CE process. The apparel associates were then asked to use their industry experience to evaluate whether the inclusion of a multi-disciplinary team in the new CE process would improve time, cost, or quality for the functional activities represented in each one of the CE conceptual statement posters. The researcher asked them to write specific comments and to circle the improvement factor. The nominal scale was based on a rating of good improvement (10) to do not know (0).

Further Re-Contextualizing Data into Computer Drawn $IDEF_0$ Diagrams

The researcher used the checklists and critiques from the apparel associate focus groups to create a generic CE apparel model. The researcher reviewed the checklists and critiques for consistency of the functional activity selection for operational statement categories by the focus group of apparel associates. The researcher drew 80 diagrams with 292 functional activities. The functional activities from the validated posters were re-contextualized into computer drawn $IDEF_0$ charts. The Topdown Flowcharter© software program was used to create the $IDEF_0$ charts. Since the functional activities had been taken out of the *as is* environment sequence, some functional activities were re-contextualized to form categorical groupings to further refine the model. The categorical groupings are located at the third $IDEF_0$ hierarchical level along with some specific functional activities. The multi-disciplinary team members and enabling technology mechanisms were added to the charts.

For each functional activity in the *to be* environment, inputs, controls, and outputs are not included on the $IDEF_0$ diagrams, because they remained constant between the *as is* and *to be* environments. For Chapter VI results, the activity numbers (e.g., A1) from the *as is* environment are written in the bottom right corner inside the apparel functional activity boxes. The numbers for the *to be* functional activities do not include an A; rather, they are referenced with a number (e.g., 112). Each apparel functional activity has a ranking. The activity rank is shown in the lower left of the functional activity box. The activity ranks are the Q-Sort results that show which activities can be accomplished early, middle, or late within each of the conceptual statement areas. A ranked number (i.e., *early* [1], *middle* [2], or *late* [3]) was added to the left corner of lower level functional activity boxes. The activity ranking provided a basis by which the researcher could compare whether the apparel activity in the *to be* environment moved from its position in the *as is*

environment. The present study did not attempt to change the inputs, controls, or outputs from the *as is* environment to the CE apparel process. Thus, an Axxx reference number that was indicated in the right corner of the lower level functional activity boxes referencing inputs, controls, and outputs remained the same. The arrows representing constraining factors were not included in the CE process, as this was beyond the scope of the present study.

Gaining Approval

The researcher followed Marca and McGowan's (1988) recommendation to have a technical review committee review and approve the CE $IDEF_0$ posters. The goal of gaining approval is to achieve consensus on how a particular system will work. Approval was gained through technical reviewers (i.e., Ph.D. committee members) who reviewed the CE $IDEF_0$ posters. Using the technical reviewers' recommendations, the researcher revised $IDEF_0$ drawings to correct IDEF syntax errors. The conclusion of data analysis was to document the changes that were made to the *as is* environment so that a CE apparel framework could be created.

CHAPTER V. RESULTS AND DISCUSSION: CURRENT DESIGN AND PRODUCT DEVELOPMENT PROCESS

Results and Discussion Overview

The purpose of the present study is to develop a CE framework specifically for apparel manufacture. The results are reported in two chapters. The results and discussion narrative of Chapter V are the researcher's description of functional areas (i.e., current apparel design and product development process and process performance weakness found in the *as is* environment. Chapter V IDEF results are presented in 101 $IDEF_0$ analytic graphic diagrams for the *as is* environment (see Figures 17 through Figure 118).

To determine the functional activities during data collection, the researcher followed Patton's (1980), Wilcox's (1972), and Malhotra's (1993) recommendations to focus on apparel associates' decisions and actions made for each apparel design and product development activity. For Phase One, the researcher used a triangulated data collection method that combined interviewing, reading company documents, and observing. The $IDEF_0$ diagram results are from interview questions which asked apparel associates the type of and sequence of functional activities. The researcher used data from observing and reading company documents to augment interview information. For each functional activity, apparel associates were asked questions to identify inputs, controls, outputs, and mechanisms. The process performance results are based on the researcher interviewing apparel associates and reading company documents on time-to-market, excess cost, and process quality. Chapter V performance measure narrative includes *as is* environment communication difficulties that provides background for Chapter VI multi-disciplinary team evaluation. Chapter VI describes Phase Two results, the development of

a *to be* environment. The integrated apparel product development process was developed using the CE approach with projected process performance improvements.

Phase One was an interpretational qualitative research design that included conducting in-depth interviews, reading company documents and observing was used by the researcher for the present study. The apparel manufacturers represented multiple merchandise classifications and were located in the Southeastern U.S. The subjects were apparel associates who were involved with apparel design and product development. Phase One results are based on data collection from 72 apparel associates.

Process Capture: The *As Is* Environment

Phase One findings follow Pawar and Driva's (1996) process capture recommendations to document the *as is* environment. The researcher adapted Marca and McGowan's (1988) and Tesch's (1990) data analysis procedures to create the *as is* $IDEF_0$ diagrams. Figures 17 through 119 diagram the results of the present study for the *as is* environment using $IDEF_0$ analytic graphic diagramming.

The *as is* environment is a sequential process in which apparel design activities occur early in the process and are handed off to the other product development functional areas (see Figure 18). The findings correspond with the first three stages of apparel design through sample production shown in Figure 2. The sequential apparel process supports Amacher et al. (1991) and Willett and Willett's (1991) definitions of apparel manufacture. The *as is* environment of transforming inputs to create final outputs is a complex process that takes place within a short time period (i.e., 32 weeks). Create apparel line (A1) depicts the design process and is the beginning of a seasonal design and product development cycle (see Figure 18). Develop colors and prints (A2) and implement fabric design and special operations (A3) are considered product development activities; however, approving fabric and colors (A223) and creating print package

(A2313) are considered design activities within these processes (see Figures 42, 47). Create garment pattern and prototype (A4), set production specifications (A5), and produce samples (A6) are considered product development activities in the *as is* environment (see Figure 18).

The *as is* environment $IDEF_0$ model begins with the A-0 boundary diagram that identifies the ICOM used in the *as is* environment (see Figure 17). The A0 diagram begins the $IDEF_0$ hierarchical decomposition and depicts create apparel line (A1), develop colors and prints (A2), implement fabric design and special operations (A3), create garment pattern and prototype (A4), set production specifications (A5), and produce samples (A6) (see Figure 18). The functional activity boxes create apparel line (A1), develop colors and prints (A2), implement fabric design and special operations (A3), create garment pattern and prototype (A4), set production specifications (A5), and produce samples (A6) are shadowed, indicating that each functional activity decomposes into lower level drawings to show further detail. The ICOM in the A-0 diagram links to the ICOM drawn in lower level diagrams. Each functional activity is numbered (e.g., Axxx) identifying the functional activity hierarchy. For example, create apparel line (A1) decomposes into develop design and business goals (A11) which decomposes into determine business plan (A111), understand marketing concept (A112), and search environment for information (A113) (see Figures 18, 19, 20).

The *As Is* Environment Functional Areas

For reports and apparel line analysis, the apparel associates explained that *as is* apparel activities are grouped into alpha-numeric categories. The apparel associates noted that activities for create apparel line (A1), and create garment pattern and prototype (A5) were identified by style codes (e.g., B123) and categorized by SBUs (e.g., sweaters). Apparel associates compiled reports by fabric codes to document color and print

development (A2) and to document fabric design and special operations implementation (A3). The activities within set production specifications (A5) were recorded by fabric codes and/or lot numbers. Activity reports for purchase fabric and findings (A51) and conduct fabric and garment QA process (A52) were specified by fabric codes. Conduct engineering process (A53) and create markers (A54) apparel activities were identified by lot numbers. The Operations department issued cuts by lot numbers for the manufacturing plant to start the sample production process (A6). To conduct cutting activities (A6231, A6232), apparel associates used fabric codes to select fabric and lot numbers to identify garment styles to cut. Apparel associates input information and used weekly reports to track sample production by lot numbers (A622) (see Figures 18, 90, 115, 116).

Apparel associates indicated that the tracking of product sales was important for apparel product lines determination for future minimum plans (A111) (see Figure 20). The findings indicated that apparel associates gauged the success or failure style codes within an SBU by sell-in and sell-out figures. Apparel associates identified sell-in as style codes which had sold to the retail accounts during a season and referred to sell-out as a tracking of style code sales from major retail accounts. The apparel associates indicated that sell-out figures provided a more realistic figure of style code success or failure since the reported figures reflected products that consumers bought during a season. An apparel associate indicated that meeting consumer needs is the number one concern, even above cost or making a niche for the company.

Create Apparel Line

Create apparel line (A1) represents the prediction decisions and the design of apparel products to develop an apparel line. Create apparel line (A1) is a launching point for all other functional activities within apparel product development. The apparel associates indicated that the majority of activities represented in Figure 4, sequential apparel design and product development, primarily took place during the create apparel

line functional activity (A1). The exceptions were final garment costing and advance manufacturing specifications (see Figures 19 through 39 for a comparison).

Apparel associates go through iterative steps to develop ideas for a seasonal apparel line. Create apparel line (A1) begins with the inputs of apparel season release date, and design inputs of reports, instructions, work kits, and reference items (see Figures 18, 19). Some outputs control later functional activities in the *as is* environment, including design controls (A1523, A1533), line sheet submission (A1633), and communication of solution (A1643) (see Figures 31, 32, 37, 39). Final outputs from create apparel line are the development of the line plan and sales package.

Create apparel line is a major constraint in the *as is* environment because many subsequent functional activities need inputs from create apparel line functional activities. The product development activities of develop colors and prints (A2), implement fabric design and special operations (A3), create pattern and prototype (A4), and set production specifications need inputs from evaluate and make decisions (A15), or specify and communicate solution (A16) in order to start their activities (see Figures 31, 36, 40, and 89 for examples). The constraints that create apparel line (A1) have on the product development process are consistent with the *over the wall* approach. An over the wall approach that is a characteristic of sequential manufacture can cause process delays (Menon, 1992b). The Regan et al. (in press) forthcoming article on the "Applicability of the Engineering Design Process Theory in the Apparel Design Process" provides in-depth results and discussion in which the functional activity create apparel line (A1) was operationalized (see Appendix A for abstract).

Develop Colors and Prints

Develop colors and prints encompasses 60 functional activities. The activities are shown in implement color process (A21), implement color piece dye process (A22), generate color printing process (A23), implement piece dye for garments (A24), and

approve dyed color samples (A25) (see Figure 40 through Figure 54). Develop colors and prints (A2) represent knit piece dye color development, woven and knit print color development, garment dye development, and color approval. Wholesale and retail market trends affect color selection, number of fabrications (e.g., textures, stripes), and finishes (e.g., prints).

The color and fabric design functional activities are accomplished internally within the apparel manufacturers' organization or externally with textile suppliers. One company was responsible for its own fabric converting in which the implement color process (A21) is accomplished by design, merchandising, and merchandise service apparel associates. Another company did not conduct fabric converting, so textile suppliers were responsible for the activities within implement color process (A21). The apparel associates used multiple independent textile suppliers to accomplish implement color piece dye (A22), generate color printing (A23), and implement piece dye for garments (A24). Multiple textile suppliers were used primarily because the textile suppliers produced a narrow range of fabrications (e.g., only knit print fabrics). Create apparel line (A1) constrains develop colors and prints (A2) because outputs are needed from evaluate and make decisions (A15) in order to start the color development process. The specific inputs needed come from finalize color palette (A1523) and finalize fabric prints and textures (A1533) (see Figures 19, 31, 32).

For each season, apparel associates develop new colors, use previously approved colors, and buy open line colors from textile suppliers. A unique color palette is created each season with newly developed colors along with previously approved colors from prior seasons. The new colors are developed specifically for each apparel manufacturer by textile suppliers. Apparel associates stated that having a unique color palette developed for their apparel lines is a competitive advantage. Offering special product features, such

as unique colors, is the use of one type of differentiation as a competitive advantage strategy (Porter, 1990a).

The primary output of develop color and prints is the transformation of the requested color standard submit into dye formulas which are used for sample and production fabrics. The output required color approval (A25). Merchandising or quality assurance apparel associates were responsible for approving the dyed color submits from textile vendors (A25) (see Figures 40, 54). The textile supplier submitted inputs that included either dyed sample standard (A223), color tab submission (A233), or dyed knit fabric piece on an approval card (A244) (see Figures 42, 47, 52). The final outputs for develop colors and prints (A2) became a step in the process to create raw materials needed for garment samples. Purchase orders, sample approval of color standards, and multiple outputs for garment samples were needed as inputs to the implement fabric design and special operations processes (A3) (see Figures 40, 41, 42, 47, 52, 54).

The numbers of fabrics used by apparel associates to develop a seasonal line were documented by the use of fabric codes. One fabric code equated to a single fabric and the completion of one cycle for develop colors and prints (A2). The seasonal number of fabric codes for piece dyed yard goods (A223) ranged from 35 to 200 per SBU for the individual apparel manufacturers. Fabrication variability impacted the number of solid piece dyed colors that needed to be developed for one season because different dyestuffs are used for different fabrications. The rework cycle for the functional activities within implement color process and develop color for piece dye process (A21, A221) was replicated for each color developed and for each fabrication used. For one apparel season, one apparel manufacturer introduced 15 new solid piece dyed colors that transformed to 50 lab dip replications (see Figures 40, 41, 42, 43, 44, 45).

The seasonal quantity for printed fabrics (A23) ranged from 60 to 100 fabric codes per SBU for the individual apparel manufacturers. The generate color printing

process (A23) required a textile vendor to develop multiple colors for each print fabric. For example, one apparel associate indicated that their company averaged seven colors per print fabric. The multiple number of colors implies that the sequence of functional activities in generate color pigment (A233) were replicated from 420 to 700 times (see Figures 40, 50, 51). Piece dye for garments (A24) were replicated approximately 35 times per season for the apparel manufacturer that used this process (see Figures 40, 52, 53).

Implement Fabric Design and Special Operations

The findings represent the process of developing rotary fabric prints (A31), engineered fabrics (A32), knit developed fabrics, full fashion sweaters (A33), and special operations and trim (A34) (see Figure 55). Implement fabric design (A3) involves 73 functional activities to transform fabric designs, dye color formulations, and raw materials into fabric for apparel garments (see Figures 55 through 72). Apparel associates defined rotary fabric prints as a print art design that was transformed into fabric by either fabric transfer printing or rotary screen printing (see Figures 56 through 64). Engineered fabric designs were defined as a designed fabric print in which stripes were placed asymmetrically on a garment (e.g., the garment's left side had stripes and the right side did not) (see Figures 65, 66). Full fashion knitting is designing and producing shaped knit garment components on knitting machines. The components are looped (i.e., not sewn) together to create a garment (see Figures 67 through 70). Circular knit textures are the development of a specialized knit (e.g., yarn dye stripe) using circular knitting machines. The circular knit textures apparel activities shown in Figures 67, 71, and 72 correspond with the first three stages described by Kadolph et al. (1993) for sequential textile product development (see Figure 3). Special operations is the creation of screen prints, embroideries, or fabric finishes (e.g., stone wash) to embellish garments (see Figures 73 through 77).

The creation of fabrics and special operations (A3) was accomplished by design, merchandising, pattern making, textile apparel associates, and outside contractors. Design and merchandising apparel associates are responsible for fabric and special operation design creation, submission, and approval. Design or pattern making apparel associates are responsible for engineered fabric designs (A32). Research and development and sample manufacturing apparel associates are responsible for full fashion knitting (FFK) (A33). Design and textile apparel associates are responsible for creating circular knit textures. Design, pattern making, manufacturing apparel associates, and outside contractors are involved with special operations.

Implement fabric design and special operations are constrained by inputs from create apparel line (A1) and develop colors and prints (A2) because the process requires inputs from multiple functional activities within these functional areas. The functional activities generate rotary printing (A31) and create knit textures (A332) require inputs of line sheet submit to purchasing (A1633). A purchase order is generated (A5113) and then is submitted to the textile vendor (A51) (see Figures 37, 92, 91). To start sample fabric production, various inputs are needed. Rotary print process (A31) requires specific inputs of print package (A231) and technical instructions (A232). Engineered fabric designs (A32) requires inputs of fabric identification (A134), reference items (A135), and carry-over garment ideas and prototype (A1413, A1414). Knit developed fabrics (A33) is the creation of a specific fabrication (e.g., texture, yarn dye stripe) for an apparel manufacturer. Knit developed fabrics requires instructions from prototype request (A155, A156), reference items and fabric ideas (A1133, A134), textures and fabric piecing (A1423), new garment prototypes (A1413), and carry-over and reorderable garments (A1414) (see Figures 54, 47, 48, 49, 24, 27, 28, 30, 22, 24, 29).

The findings indicate that the number of fabric prints and special operations depended on the apparel product line developed and on market direction. The functional

activities of generate rotary prints (A31), create engineered fabrics (A32), and create knit developed fabrics (A33) consisted of one complete cycle for each fabric created. The replication of these functional activities are documented by the number of fabric codes used in one season. One fabric code equals one complete cycle. For example, an SBU that had 40 prints developed seasonally means that the 39 functional activities within generate rotary print cycle (A31) repeated 40 times. Engineered fabrics and knit developed fabrics had an average replication of less than 10 designs developed per season. For each special operation style designed, the sequence of functional activities for develop special operations (A34) was replicated. Seasonal SBU special operations (e.g., embroideries, screen prints, wash codes) quantities ranged from 5 to 75 per season (see Figures 73, 74, 75, 76, 77).

Create Garment Pattern and Prototype

Create garment pattern and prototype (A4) involved 60 functional activities to transform design sketches or reference garments, instructions, and specifications into a garment prototype. The specific stages of garment pattern and prototype are to create basic pattern blocks (A41), create new styles (A42), create carry-over garments (A43), develop prototypes (A44), and grade patterns and submit instructions (A45) (see Figure 78).

Create basic pattern block (A41) is an on-going process for new product lines and new fabrications. One basic pattern block is created for each SBU apparel classification (e.g., oversized shirts) and fabrication type (e.g., jersey knit). Basic pattern blocks are used to improve garment manufacturability and for consistency in specifications. To begin a basic pattern block, the pattern apparel associates required a design input of product line definition (A1122). When the basic pattern block is completed, the product line definition is written on a style description sheet (see Figures 21, 80). A pattern

apparel associate uses the basic pattern block output as an input to create new styles (A42) or carry-over garments (A43) (see Figures 78, 79, 80, 82, 85).

Create patterns and prototype (A4) replicates for each new garment style created. New apparel style development involved the functional activities of create new styles (A42), develop prototype (A44), grade patterns, and submit instructions (A45) (see Figure 78). The number of replications for new styles depended on whether the SBU developed a basic or fashion-oriented product. An SBU that created a basic product replicated the sequence of create new styles (A42), develop prototype (A44), and grade patterns and submit instructions (A45) functional activities approximately 15 times, whereas a fashion-oriented product line replicated the sequence over 80 times (see Figures 82, 83, 84, 86, 87, 88, 89).

Carry-over garments are styles previously produced and sold by an apparel manufacturer in which garment components and fabrics are modified for a new seasonal line. Apparel associates used carry-over garments for basic reorderable garment styles, previous best-selling garment styles, or engineered fabric design garments. Specific functional activities involved are to create carry-over garments (A43) and to grade patterns and submit instructions (A45) (see Figure 78). For a carry-over or reorderable garment, the create pattern and prototype process replicates for each style change. Apparel associates defined a style change as a pattern modification from an existing style for construction, size, fabric type, or garment component detail (e.g., pocket) (see Figures 78, 85). A prototype was not always sewn for carry-over styles, and the need to sew a prototype depended on the type of pattern modification or fabric change. The number of new styles versus carry-over garments for an apparel line depended on market direction and other influential factors which varied from season to season. For example, the apparel associates for one apparel manufacturer seasonally developed 45% of its styles using carry-over garment styles and 55% new garment styles in the product line.

The primary purpose of request and develop prototype (A44) is to sew a new or carry-over test garment for design and engineering approval (see Figure 78). A new prototype style is reviewed and approved by designers, pattern makers, engineers, and manufacture apparel associates (A4435) (see Figure 88). The findings indicated that after the prototype review (A443), a designer often requested pattern changes and a new prototype (see Figure 85). A new garment style often needs several revisions, which replicates the cycle of revise patterns (A424), sew prototypes (A442), and review prototypes (A443) two to five times (see Figures 85, 86). Upon prototype design approval (A4435), the patterns are graded into multiple sized patterns (A45). Marker and construction instructions are then written (A455) and become inputs to create markers (A54). The pattern and marker making computer systems were networked so that graded patterns were sent electronically to marker making (see Figures 88, 89, 107). New garment style prototypes were sent to manufacturing plants. The manufacturing apparel associates reviewed prototypes to determine equipment needs and tooling needs based on the prototypes' standard operations and nonstandard operations (A6111, A6112) (see Figure 113).

Set Production Specifications

Set production specifications encompasses 92 functional activities shown in purchase fabric and findings (A51), conduct fabric and garment quality assurance, (A52), conduct engineering process (A53), and create markers (A54) (see Figure 90). The apparel associates involved with purchase fabric and findings (A51) are responsible for generating reports, communicating with textile vendors, and writing and sending purchase orders. Fabric buying apparel associates are responsible for tracking the fabric codes described in develop colors and prints (A3) and implement fabric and special operations (A4). To initiate the purchase order process, the fabric buying staff needed inputs from the functional activities of evaluate piece good quality (A224), evaluate color

quality (A2213), create knit textures (A3323), select trim and findings (A341), and queue and distribute special operation (A346) (see Figures 42, 43, 45, 71, 73).

The conduct fabric and garment quality assurance process (A52) involves conducting quality assurance (QA) tests for raw materials and sample garments. All of the apparel manufacturers had unconditional product warranties, so QA testing and/or vendor certification was considered important by apparel associates. To test piece goods, QA needed inputs from print first production run (A3142) to start their process (see Figures 63, 91, 92). Not all sample fabrics were tested. The testing of raw materials depended on vendor certification, fabric finishing types, and the textile vendor's past record of product reliability. A QA apparel associate indicated that print fabrics were almost always tested, because printed fabrics had the least consistency in passing QA tests (see Figures 95, 96). Small quantities of finished sample garments were tested for meeting QA appearance (e.g., no dye streaks), construction, and specification requirements. Quality apparel associates identified garment quality problems for multiple fabric types and new fabric types (see Figure 98).

The conduct engineering process (A53) involves translating style numbers into lot numbers for sample and production assignment, conducting costing, and creating specifications (see Figures 90, 99). The engineering process (A53) needed inputs to start their process from merchandise plan (A111), piece good test request (A1424), line sheet (A1633), and pattern specifications and instructions (A455) (see Figures 20, 29, 37, 89, 98).

The design and merchandising apparel associates requested piece good and test cuts for several reasons: to increase the cost efficiency for a garment component (e.g., collar), to try a new garment component styling change (e.g., pocket), to try a new raw material type for the company (e.g., Turkish yarn), or to try a new textile supplier's products. The purpose of the test cut and piece goods testing process (A531) is to

evaluate whether existing equipment and operations are suitable for fabric and garment changes within an apparel line. An example of testing a fabric and garment change is sewing hem types for a new fabric. Replication of the test cut and piece good process is generally low; however, if a new apparel line is introduced by a manufacturer, the testing replications were increased (see Figure 100).

For each line sheet submitted (A1633), the engineering process sequence is replicated for functional activities in assign sample production (A532), generate style development (A533), and generate samples (A534). The primary outputs for the engineering process were style description sheet and garment sample. During style development (A533) engineering apparel associates entered information from line sheets into the computer system so that a garment design became a manufacturing style. A wide range of manufacturing style quantities were produced by the apparel manufacturers. The SBU seasonal manufacturing style quantities ranged from a low of 25 for a basic apparel product to a high of 350 for a fashion apparel product. Each manufacturing style was assigned to a plant for sample production, and direct costs were calculated (see Figures 101, 105). Engineering apparel associates compiled a sample package which consisted of patterns, specifications, style descriptions, and instructions (see Figures 103, 104). The sample package and plant assignment became inputs for sample production (A61).

Two of the apparel companies used a computerized marker making process. Create markers (A54) combines pattern pieces, patterns, and instructions to create an output of an electronic stencil (i.e., computer controlled cutting). The markers were created on a CAD system and sent electronically to production plants (see Figure 107). The inputs needed were a line sheet (A1633), cost marker completion (A454), and pattern instructions (A455) (see Figures 37, 89, 107). Multiple markers were made for each garment style. The findings indicated that the number of markers made varied depending on the size range, quantity, fabric width, and special pattern instructions.

Produce Samples

The process of producing samples brought together inputs of markers, fabrics, special operations, and findings to create a sales sample. To produce the samples, the inputs needed are from assign sample production (A532), generate style development (A533), generate samples (A534), create specifications and sample package (A5341), and cut issuance (A545, A5453) (see Figures 99,101, 102, 103, 104, 107, 110). Engineering apparel associates assigned garment sample production to the domestic manufacturing plants. Sample production often had to be reallocated to balance out plant assignments (see Figure 101). The sample packages compiled during the engineering process (A5341) were sent to a sample coordinator to sew the samples (A621) (see Figures 103, 104, 115). Garment sample production for the apparel manufacturers ranged from 360 garments to 18,000 garments. The number of garment samples produced depended on the type of operation (e.g., mail order, retail store), the number of sales representatives, and the number of samples needed for internal review. Garment samples are made on production equipment in a flexible sewing unit or hand carried through the production line. A separate sample production line was not used because apparel associates indicated there was not enough quantity to warrant it.

Summary of *As Is* Environment Functional Activities

The *as is* environment is a sequential process in which apparel design activities occur early in the process and are handed off to other product development functional areas. Syan (1994) noted that in sequential manufacturing, each stage is taken in turn and requires that the next step in the sequence does not start until completion of the previous step. Create apparel line (A1) is a major constraint in the process in which all of the other product development functional activities (A2, A3, A4, A5, A6) need inputs to start their process.

The findings indicated that some manufacturability issues are considered in the *as is* environment. A variety of apparel associates from design to manufacturing were involved with reviewing new prototypes. For new garment styles, multiple prototypes were sewn (A442) and reviewed (A443), and patterns were revised (A424). The review and revision process is in concert with the design for manufacturability goal to improve manufacturability and assembly during the design process (Boothroyd, 1992).

In the *as is* environment, there were common rework cycles that occurred: in the design process at identify questionable bodies (A1613); during develop colors and prints at approve color (A223, 22125, A244, A252); during implement fabric and special operations at approve strike off (A31433) and approve mending (A3435); in set production specifications at generate and evaluate change orders (A354), and approve marker (5444); and in produce samples at request pattern marker change from manufacturing (A614).

As Is Environment Process Performance

Upon completion of verification of an organization's *as is* environment, the next step is to analyze the gap between the *as is* and the *to be* environment (Pawar & Driva, 1996). To accomplish this, the researcher used Carter and Stilwell-Baker's (1992) and Pawar and Driva's (1996) recommendations to use performance measures to guide questioning on what needed improvement in the *as is* environment. The results presented are the inefficient activities that generated rework, process delays, or excess costs, and which attributed to performance weaknesses in the *as is* environment.

The researcher combined Duffey and Rosen's (1994) and Prasad's (1996) performance measure definitions and categories that emerged from the data to present results on performance measures. The process performance measures analyzed are time-to-market (i.e., flow of activities), excess cost, and process quality. The present study

used the line development calendar as a guide for interviewing apparel associates on time-to-market delays. Through the data collection process, the researcher found that quantitative measures for cost and process quality were not used by the sample for the design and product development process. Process quality and cost analysis in the present study were restricted to implied increased cost and implied decreased process quality as documented by the subjects.

Time-to-Market – Flow of Activities

Duffey and Rosen (1994) defined time-to-market delay as an iteration of design and pre-production activities that cause a delay so that a product does not reach market when expected. The apparel associates tracked product development time by the use of a line development calendar. This method of tracking the process by using a line development calendar is consistent with Glock and Kunz (1990). The product development calendar was used as a scheduling guide; however, during data collection the apparel associates stated they were often *off-calendar*, specifying that they were behind schedule. The apparel associates indicated that the apparel season release date (i.e., date sent to sales representatives) was very important. Hence, even if the apparel associates were *off-calendar* during the product development cycle, an effort was made to ensure that the garment samples were shipped to the sales representatives on time, even if this effort increased cost.

Apparel associates were asked the same lead question for time-to-market: How much variation have you experienced in the time required for xxx (e.g., the merchandising) process? (See Appendix D for data collection instruments.) The findings indicated that time-to-market process delays in the *as is* environment are primarily created by (a) weak product ownership, (b) poorly coordinated communication between design and product development functional areas, and (c) late and bulk line sheet submission.

In the *as is* environment, process delays result due to some of the apparel associates in the product development areas not making needed decisions (i.e., weak product ownership). Some product development apparel associates pushed decision making back to the design and merchandising apparel associates. For example, if a fabric was substandard (A52113) and did not pass a QA textile test, the QA Manager did not contact the textile mill; rather, the QA manager requested that the merchandiser call the textile mill. The phone tag creates process delays since at this point in the line development calendar, the merchandiser is working on a different season. The merchandiser may be traveling and unavailable to answer QA questions in a timely manner (see Figure 97). The above example of weak product ownership is an illustration of the *over the wall* approach as described by Menon (1992a).

The findings indicated that poor coordination of communication resulted in rework and time delays. Pattern making apparel associates noted that communication problems are due to inaccurate or incomplete visual style communication and design and merchandise apparel associate unavailability. Regarding incomplete visual communication, one apparel associate commented, "...this sketch came in with the prototype sheet minus all the writing except for use surplus twill was all the information we had. Button was circled and button hole, that was it.... This sketch and that little bit of writing, we were supposed to do whatever." Another apparel associate stated, "I know when I get it [the sketch], that it's not going to be right. If I called over there every time they [designers] sent me something that was not right, I'd spend my day on the phone." In response to designer or merchandiser unavailability, a pattern apparel associate stated, "Things work best when you sit down and talk about things; it's when she is traveling and you second guess...."

The findings show that design and merchandising apparel associates' response to the wholesale and retail market was an impetus for some major apparel line changes in

fabrication and garment styles. The apparel associates' reaction to market demand supports Dickerson's (1991) premise that response to consumer demand can challenge apparel manufacturers since consumer interest can change quickly. Making apparel line changes in response to markets supports Blaich and Blaich's (1993) opinion that product design often is a primary factor in differentiating one product from another. However, product development apparel associates indicated that some major changes in an apparel line were not communicated to them on a timely basis, which created delays in the process. An engineering apparel associate noted that sometimes, if design apparel associates are late in communicating design changes, it had a trickle-down effect of changing patterns, revising markers, and possibly recutting the stencils. For example, one designer introduced a new apparel line requiring new pattern pieces. Manufacturing apparel associates were not aware of the change until receipt of the sample package (A621) (see Figure 115). Manufacturing apparel associates were not able to use regular routing and automated equipment due to the garment's construction. In addition, the sewing operators had difficulty sewing the garment components when using manual sewing equipment.

In the *as is* environment, design and merchandising apparel associates are overburdened with decision making that create peak submittal of inputs needed for other product development areas. For each season, design and merchandising apparel associates are typically responsible for 50-350 selling styles (i.e., individual garment styles). A quote from an apparel associate describes typical daily decisions.

> You always usually have three particular seasons that are in different stages. This work-in-progress stage for each season overlaps. You have something that's in the showroom right now that is in the process of being sold...you are making any corrections so that production will be exactly what it is supposed to be.... Along with that, you have the beginnings of

correcting what is going to be in the showroom for the next season....

Then you are doing the beginning research for the next season.

Many apparel associates stated that bulk submission of line sheets created process delays. For example, if the engineering department received 50 line sheets in one day, all of the line sheets could not be processed at once. It typically took 30 minutes for an engineering apparel associate to process each line sheet. By the time the apparel associate processed line sheet number 50, it had waited 25 hours (see Figure 102). Some apparel associates felt increased pressure to perform their jobs due to *off calendar* status of the line development calendar. The late and bulk submission of line sheets created additional flow problems in pattern making, prototype sewing, and QA.

The findings revealed that the number of seasonal fabrics (i.e., 35 to 200 fabric codes) for an SBU were ordered within a short time period (e.g., one week). The late and bulk ordering of fabric caused time delays in the *as is* environment. The bulk ordering of textile prints created process flow problems. A textile apparel associate noted that it was detrimental to the engraving and printing process when 40 fabric print orders were received at the same time. Textile engraving and engraving throughput depends on the number of colors (i.e., screens). For example, an engraver's in-house capacity may be 200 colors in a week (e.g., 25 jobs of 8 screen fabric prints). Freelance textile apparel associates sometimes enable the engraver to get the 200 colors out quickly (see Figures 56, 57); however, the use of freelance artists increases textile supplier costs. If the textile engraving house rushes the order, then all the fabric arrives at the apparel manufacturing plant at the same time. The bulk arrival of fabric then negatively impacts the sample production process (A6) that needs a staggered sample production schedule (see Figures 116, 117).

The line development calendar allowed for a staggered schedule of four weeks for design associates to submit line sheets to start the sample production scheduling process.

Manufacturing apparel associates stated that there are peaks and valleys of demand, and that the majority of sample packages (i.e., an input) are received at the end of the four-week window. This situation created a rush to produce garment samples (see Figures 115, 116). By receiving the bulk of sample packages at the end, manufacturing apparel associates said that cutting, sewing, and special operations of samples were consistently rushed through the process to meet the on-sale date deadline. As noted by a manufacturing apparel associate, manufacturing had "their backs up against the wall" to get garment samples out at any cost. Occasionally, the apparel manufacturers used nonstandard transportation (i.e., Fed Ex) because the company was *off calendar* and had to rush garment samples through production to meet the on-sale date (i.e., time-to-market). This *off calendar* situation increased the expense to ship samples by thousands of dollars.

One manufacturing apparel associate pointed out that requests for inside special operations for garment samples were submitted in peaks and valleys. The peak and valley submission caused line balancing problems for the embroidery operators and excess manufacturing labor costs in which the operators either did not have work or were inundated with work load demand and paid over time. Duffey and Rosen (1994) referred to this type of situation as the consequence of a design decision that increases production costs.

An additional challenge is the timing for receipt of carry-over and new garment samples. Manufacturing apparel associates indicated that during the first week they primarily received carry-over garment sample requests and received most new garment sample styles towards the end of the four-week window. One manufacturing apparel associate labeled carry-overs as the *dumb, dumbs* because manufacturing could produce them blindfolded. Manufacturing apparel associates noted new garment sample styles are the most challenging, because they have new patterns, markers, routings, specifications,

style description sheets, and bill of materials. When new garment sample styles are rushed through production, it allowed very little opportunity for manufacturing apparel associates to learn how to produce them for full production. By rushing garment samples through sample production, the apparel associates commented that mistakes were found during full-production when production volume is greatly increased (e.g., 36 samples versus 10,100 garments per manufacturing style). The ability for manufacturing to learn early in the process is important for error-free assembly, as emphasized by the CE approach (Menon, 1992b).

Excess Cost

Excess cost is expense that is associated with waste from inventory, complicated manufacturing systems, overhead, rework, and operating expenses (Prasad, 1996). During data collection the researcher discovered that product development costs were not individually accounted for; rather, they were allocated as company overhead costs. To evaluate excess cost, the researcher used a qualitative approach. Apparel associates were asked the same lead questions on excess cost: When is your process inexpensive and when is your process expensive? (See Appendix D for data collection instruments.) The findings indicate that the *as is* environment had many excess costs. The excess costs were primarily due to (a) a predominant focus on direct costs rather than total costs, (b) use of industry accepted cost practices, (c) work-in-process errors, and (d) use of final inspection.

The apparel associates used traditional apparel industry accounting of calculating direct costs (A53441) and indirect costs (A53442) (see Figure 105). Direct cost accounting is calculated near the end of the product development cycle. However, traditional cost accounting does not capture hidden costs (Blanchard & Fabrycky, 1990; Carter and Stilwell-Baker, 1992). In the *as is* environment, the design apparel associates had limited access to production costs during the design phase. Hyeon et al. (1993) and

Syan (1994) contend that designers need to have access to cost during the design phase because if designers have limited knowledge of production, their design decisions can increase production costs. In the *as is* environment, design apparel associates did not know the direct cost of special operations until screen print or mending (i.e., embroidery) completion (A3435, A3454). Late cost knowledge was a reason that special operations were changed or dropped. Apparel associates stated that a product goal is to be within a pre-selected margin. At the approve mending functional activity (A3435), a design apparel associate may reject a mending after completion because its direct cost made the garment too expensive (see Figures 75, 76). In the *as is* environment, garments were evaluated based on margin requirements (A53443). At functional activities, calculate margins (A53444) and review cost sheets (A53445), garments with low margins were either changed (e.g., embroidery eliminated) to improve margin requirements or dropped from the apparel line (see Figure 105). However, as one apparel associate noted, embroidery may be why the consumer buys the garment and stated "...who cares, unless the garment sells."

Another excess cost in the *as is* environment is attributed to industry accepted cost practices such as commercial match (i.e., 5% +/- dye match) and allowable percent defects (i.e., working loss) (see Figures 45, 54, 64). The findings indicated that it was common for textile manufacturers to add a 5% working loss to wholesale fabric prices. A working loss includes irregular fabric finishing such as shading and shrinkage. The apparel associates needed to buy minimum orders that varied by fabric type and textile vendor. The industry practice of working loss is expensive for both textile suppliers and apparel manufacturers. In discussing working loss, a textile apparel associate indicated that textile suppliers purposely overproduce quantities to compensate for working loss by stating, "I produce what I believe is going to give me 5,000 yards...say I put 6,000 yards in to give me 5,000, which is more than enough because I am allowed to over ship a little

bit." A textile manufacturer would expect a 5% working loss of 350 yards on a 7,000 minimum yardage order. A wholesale fabric cost of $2.60 a yard creates a working loss of $910.00, which is a cost added to the fabric price charged to the apparel manufacturer.

Work-in-process errors creates excess costs. In the *as is* environment, a predominant practice is to inspect quality out of raw materials rather than build quality into the process or product. Apparel associates identified textile engraving mistakes as one work-in-process error. For example, a missing detail that is on a fabric standard is missing on the strike-off fabric (e.g., an animal print with some animals missing one eye). Engraving errors create excess costs in rework and the design apparel associates need time to identify errors. Design apparel associates or textile design room managers review the strike-off specifically checking for errors (see Figures 63, 64). The review may involve having the design associate travel to the textile printing location (A31423, A3143) (see Figures 63, 64). Engraving errors are a reason for strike-off rejection and the textile vendor must correct the mistake. The rework involves repeating some steps in engraving (A311, A312) and repeating all steps in print sample fabric (A313) or print table strike-off (A3141) (see Figures 56 through 64).

Many work-in-process errors are identified at the sample production stage (A6). Some problems discovered by manufacturing apparel associates during the evaluate cutting and sewing problems functional activity (A613) are pattern piece problems, incorrect marker layout on stencils, and incorrect cuttable fabric width (see Figure 155). Manufacturing apparel associates would request a pattern/marker change (A614) and the instructions would be to revise the pattern (A424, A435), submit new marker instructions (A455), and revise markers (A5435, A5445) or re-cut stencils (see Figures 82, 85, 89, 108, 109, 117). Excess cost is generated by these labor costs and wasted fabric. A manufacturing apparel associate indicated that a woven fabric's stretch and recovery textile properties were a frequent problem that created assembly problems and required

remaking patterns. If a pattern problem is not identified until sewing, the patterns have to be re-made, the marker re-laid, the fabric re-cut, and the garment sample re-sewn. In addition to excess cost, this rework also causes time delays. This rework example supports Carter and Stilwell-Baker's (1992) presumption that time delays are another hidden cost component.

The practice of final sample inspection created excess cost. Manufacturing apparel associates noted that garment pieces with fabric and/or sewn defects may continue through the production line until final inspection to keep bundle integrity. For samples, final inspection can be detrimental. An apparel associate noted, "[QA] is expensive to do a repair or to decide it is not first quality because you have to spend extra money doing a repair to get it into first quality condition or you are going to get substantially less for it when you sell it, if it is not a first quality garment."

The cost to produce the garment sample with little or no sales potential is another form of hidden cost in the *as is* environment. An apparel design associate commented on reviewing garment samples by stating "... I had one garment with the wrong collar, it should have been a smooth edge and it was scalloped and on a boy's garment a scalloped collar is not really desirable." However, when a garment sample is incorrectly produced, the pressure of getting the garment to sales representatives for the on-sale date did not allow time to remake the sample garment. An incorrect garment component on a garment sample (i.e., wrong collar on garment) would have an accompanying correction sheet indicating that the correct version is shown on the CAD sales sheet. However, the incorrect garment sample may be a deterrent to the garment's sales potential. One apparel associate indicated that sales representatives used their personal opinions in selecting garment samples to sell and would not take incorrect or unattractive garment samples on the road to show to potential retail accounts.

Process Quality

Process quality is defined as design attributes that affect a manufacturing process which limit scrap, rework, and inspection (Duffey & Rosen, 1994). Nonvalue-added activities, such as multiple versions of the same process, are company functions that are not valuable to a customer (Hammer, 1996) and contribute to decreased process quality. In the present study, reduced process quality is an output of a functional activity that could not go forward without correction and created nonvalue-added activities or rework cycles. Apparel associates were asked the same lead questions for process quality: How do you know if the xxx (e.g., engineering) process is correct and how do you find out whether the xxx (e.g., pattern making) process is correct (who tells you)? (See Appendix D for data collection instruments.) The most frequent responses from apparel associates were either "No one screams" or "I don't hear anything." The findings showed that decreased process quality in the *as is* environment was due to rework activities, nonvalue-added activities, and process delays. The decreased process quality was primarily due to (a) lack of partnership agreements between some apparel and textile manufacturers, (b) design decisions that created rework or nonvalue-added activities, (c) weak communication, and (d) the use of textile industry standards such as commercial match.

Two of the apparel manufacturers had partnership agreements with some of their textile suppliers and all of the companies had vendor certification. The findings indicated that process quality was decreased when there were no partnership agreements between apparel manufacturers and textile suppliers. A partnership agreement allowed for faster turnaround time and improved product quality. A textile apparel associate noted that sample fabric is shipped in two weeks with a partnership arrangement, and sample fabric is shipped in five weeks without a partnership arrangement. The apparel associates said that process quality is increased by having vendor certification. Vendor certification is a guideline in which textile suppliers guarantee specific textile quality specifications.

Vendor certification eliminated the nonvalue-added activities of duplicate QA testing. However, the apparel manufacturers had guidelines for acceptance of substandard fabric which did not meet vendor certification guidelines (A52113) (see Figure 97). A manufacturing apparel associate commented that the practice of accepting substandard fabric created spreading and cutting problems.

During create apparel line (A1), apparel associates holistically made decisions to determine volume product potential for garments within an apparel seasonal line. Merchandising apparel associates noted that constraints required by some textile suppliers (e.g., minimum orders) increased the risk that a garment in an apparel line would sell enough volume to risk investment (A5111) (see Figure 92). For example, an apparel associate stated, "When I buy that [fabric] I have to buy 35,000 yards at a time...and that is 1,600 shirts in one color. That's a lot of shirts...." Restricting minimum fabric orders is one reason merchandising apparel associates solicited opinions from key account retail buyers and sales representatives to identify and predict questionable garment styles or weak selling styles (A1613, A1643) (see Figures 36 and 39). For two of the apparel manufacturers, the prototypes were complete when presented to retail buyers and sales representatives at the end of the design process (A1611). In the *as is* environment, late feedback from key account retail buyers and sales representatives contributed to nonvalue-added activities and rework cycles. Rework was created when the completed prototype was revised or dropped at identify questionable bodies (A1613). A revised prototype was returned to the merchandise the line functional activity (A151). If a completed prototype was dropped, all activities in creating that garment were nonvalue-added (A42, A423, A44, A442) (see Figures 36, 82, 84, 86, 87). To reduce this rework cycle, apparel associates from one of the apparel manufacturers showed fabric and theme concepts earlier in the process to retail buyers. These apparel associates mentioned that a

disadvantage of showing fabric and theme concepts was that the retail buyers had difficulty in visualizing the garment.

Pawar's (1994) premise that problems can occur if a supplier's specifications are assumed to be correct and not checked for accuracy was supported in the *as is* environment. A manufacturing apparel associate described a problem with cuttable width in which textile suppliers will inform operations apparel associates that a fabric's cuttable width specification is 58″. A marker is then made with a 58″ cuttable width. However, when the fabric is received at the apparel manufacturing plant, the cuttable width may be 57″. This situation makes the marker incorrect and delays cutting fabric because the markers have to be remade. Late changes in the apparel line attributes to rework. An apparel associate referred to change orders with, "Here she changed the fabric code.... Many times when you change the fabric, it's a different width, so we have to order a new stencil [marker]."

Engineering and manufacturing personnel participate in line freeze (A1642) and bring up potential manufacturing problems to design and merchandising apparel associates. However, changes are not made until later in the product development process during review prototype manufacturability (A4434) and revise pattern and prototype (A444) (see Figures 39, 88, 86). The practice of waiting to make changes creates rework for pattern making, prototyping, and designing.

The findings supported the prediction by Hyeon et al. (1993) that early design decisions have a significant effect on a product's manufacturability, quality, and cost. A manufacturing apparel associate described the manufacturing impact of a design decision. "We did prototypes...but until we actually ran the fabric that was supposed to be used in that product we didn't recognize that there was going to be a problem. Stripes showed through the white placket, so we had to re-design at that point [during full production] after we had made X number of irregulars..."

Color development required a high volume of rework in the *as is* environment. Communication problems were one reason for the rework cycle at the functional activity approve color process (A252) (see Figure 54). Miscommunication sometimes occurs between textile colorists, design, and merchandising apparel associates. A textile apparel associate stated, "We do not speak the same language." Often color communication problems were due to the differing dye color effects from varying fiber contents. For example, designers often submit a color standard in different fiber contents than the fabric that will be dyed. A designer who has submitted a 100% rayon fiber content may request a shiny blue using 100% cotton. The textile colorist may know before starting work that a shiny 100% cotton is technically not feasible. The dyed 100% rayon will produce a shiny blue, while a dyed 100% cotton fiber content will produce a dull blue. At this stage, the colorist in the *as is* environment develops the color even if he/she knows the lab dip would not be what the design apparel associate wants. When approving color (A252), the design or QA apparel associate generally rejects the submit and requests a new lab dip. Figures 42, 44, and 54 illustrate that color could be rejected at color approval functional activities by the textile QA department (A223), by the textile colorist (A22125), or by the apparel manufacturer's QA staff (A252). This common rework cycle typically replicated three to ten times for each color standard submit.

Nonacceptance of the color submit and the creation of rework cycles are also common for color printing (A31433) and piece dye for garments (A2445) (see Figures 53, 64). A rework cycle commencing at approve color (A252) looped back to generate color pigment (A233) (see Figures 54, 47, 51). For piece dye for garments, a rework cycle commencing at approve color (A252) looped back to create color recipe (A243) and create dye for garments (A244) (see Figures 52, 53, 54).

Design and product development impact manufacturing more than any other singular process. During design, the majority of a product's cost and quality decisions

take place before the product is released to manufacturing (Wheelwright & Clark, 1992). However, some apparel associates did not have the opportunity to learn and relay potential assembly problems in the *as is* environment. The findings indicated pattern making and prototype sewing are rushed through so apparel associates did not have the opportunity to provide comments or relay potential assembly problems to manufacturing apparel associates. Pattern apparel associates indicated that excess work is created by singular pattern revisions rather than multiple pattern revisions (i.e., change hem length for the first request and change neckline for the second request).

The engineering apparel associates emphasized that better communication would improve process quality. One engineering apparel associate stated "...we would save time and money by insuring face-to-face meetings between design, pattern making, and engineering." The engineering apparel associates indicated that process quality would be increased if they had early communication between design and engineering apparel associates with face-to-face communication. The engineering apparel associates commented that reviewing style development requests (line sheets) and having more information available electronically with on-line software programs would decrease errors in the *as is* environment. Engineering apparel associates noted that meetings are better than the miscommunication that occurs when design apparel associates write down on paper what they want, then send copies to engineering and pattern apparel associates.

Sample assessment forms are used to identify manufacturing and construction problems; however, communication problems can still exist. A manufacturing apparel associate stated "... the purpose [of the sample assessment form] is good but we can't always get people to write and make comments, even though we are told that any cost change must be done during sample production." Another apparel associate noted that the skilled operators will more readily identify sample problems. Yet, sometimes the

comments written on sample assessment forms by operators are vague, with comments such as "this is hard to do" or "there's got to be a better way."

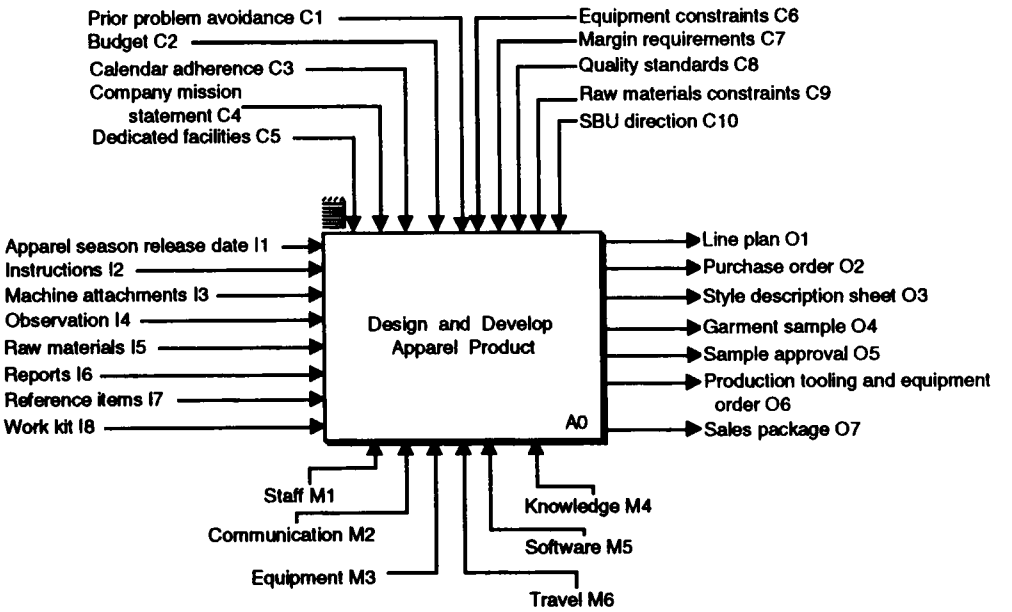
The use of a textile industry standard called commercial match, used in the *as is* environment, is both a cost and process quality problem. In addition to cost problems, commercial match (e.g., +/- 5% color standard) can create a decreased process quality called snowballing. Snowballing is a problem associated with dyeing two different textile fabrications. In an apparel line, coordinate garments frequently have differing fiber contents or fabrications. Several textile suppliers are often used to create matching dyed piece goods and fabric prints for a coordinate garment. When the fabrics are dyed or printed, one textile supplier could have a fabric with 5% stronger dye color (e.g., +5% color standard). A second textile supplier could have a fabric with a 5% weaker dye match (e.g., -5% color standard). This creates snowballing: a 10% dye variance differential during full production of non-matching dye colors in a coordinate garment. If a merchandising or QA apparel associate anticipated that the color submit would not match a coordinated fabric due to commercial match, he/she would reject the color submit at the approve colors functional activity (A252) (see Figure 54). Apparel associates stressed that color development was one of the most challenging areas in terms of time needed, costs involved, and controlling excessive rework.

Summary of the *As Is* Environment Process Performance

The *as is* environment had time-to-market delays, excess cost, and decreased process quality. The primary time-to-market delays were due to weak product ownership, poorly coordinated communication between design and product development functional areas, and late and bulk line sheet submission. The primary reasons for excess cost in the *as is* environment were a predominant focus on direct costs rather than total costs, use of industry accepted cost practices, work-in-process errors, and use of final inspection.

Decreased process quality in the *as is* environment was primarily due to lack of partnership agreements between some apparel and textile manufacturers, design decisions that created rework or nonvalue-added activities, weak communication, and the use of industry standards. The performance weaknesses of time-to-market delays, excess cost, and process quality were not mutually exclusive in the *as is* environment. Examples provided in results showed that time-to-market delays (e.g., off calendar) increased product development costs.

The need to improve communication was emphasized by apparel associates during data collection, and examples of poor communication coordination are provided in the results. The apparel associates did not address many manufacturability issues for color development, fabric development, pattern creation, and prototype assembly during the design phase create apparel line (A1). By not addressing manufacturability issues for colors, fabrics, patterns, and prototypes, the result was peaks and valleys of demand, increased time-to-market, and increased rework cycles.



Purpose To document the current "as is" apparel design and product development process for use in identifying the sequential flow and process performance

Viewpoint: Ph.D. student/analyst based on interviews of actual apparel and textile firms

NODE: A-0

Figure 17. Top level drawing.

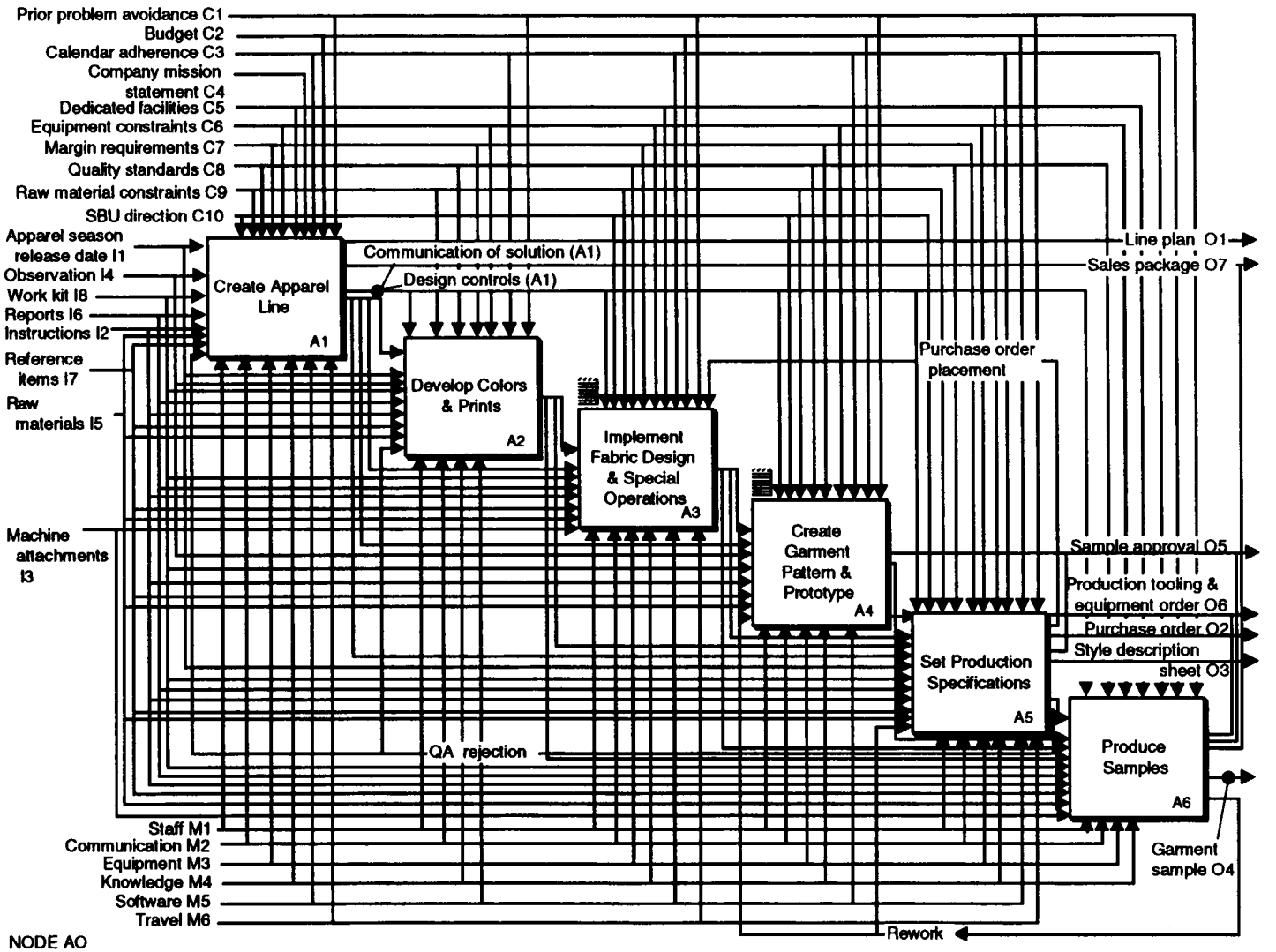


Figure 18. Design and develop apparel product.

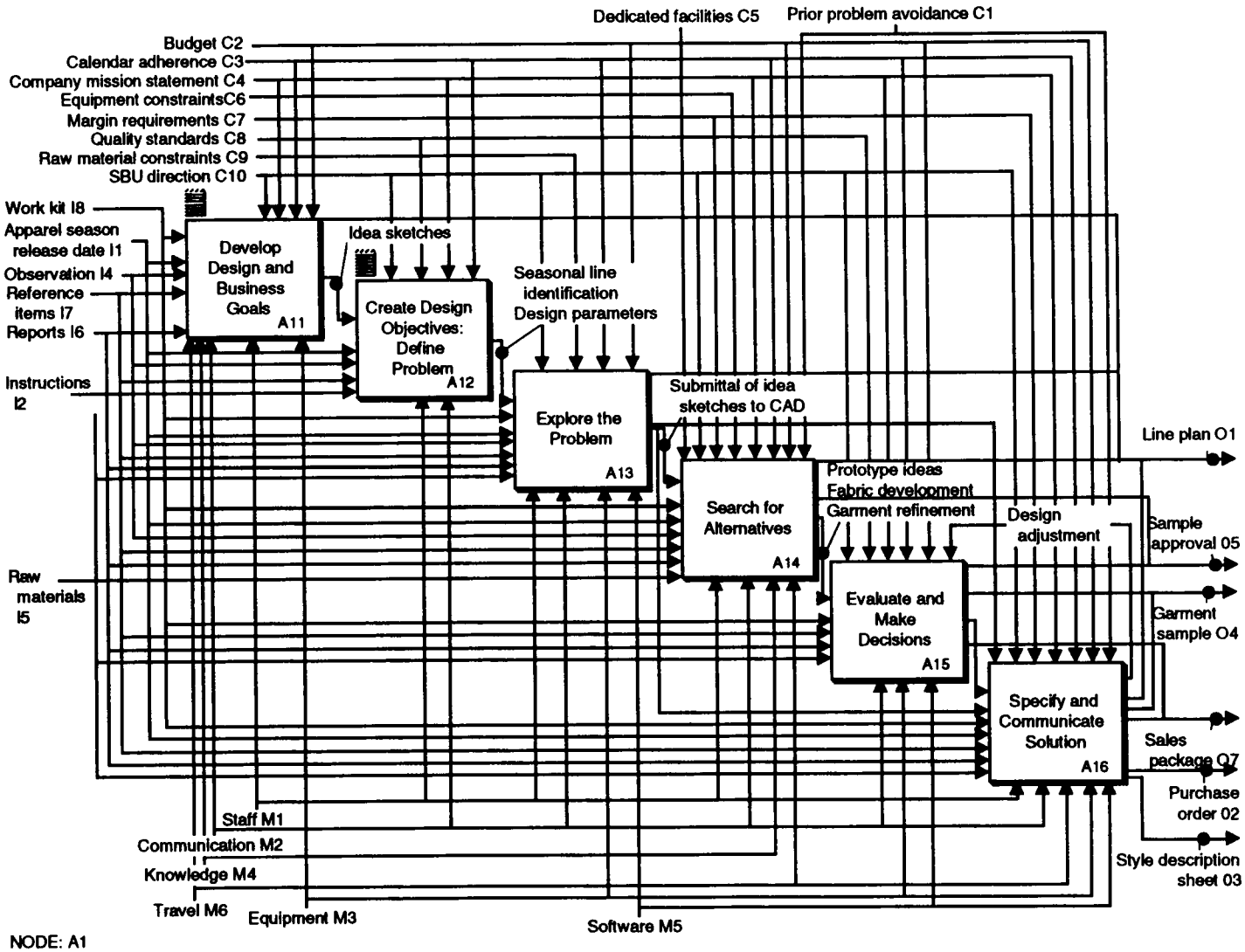
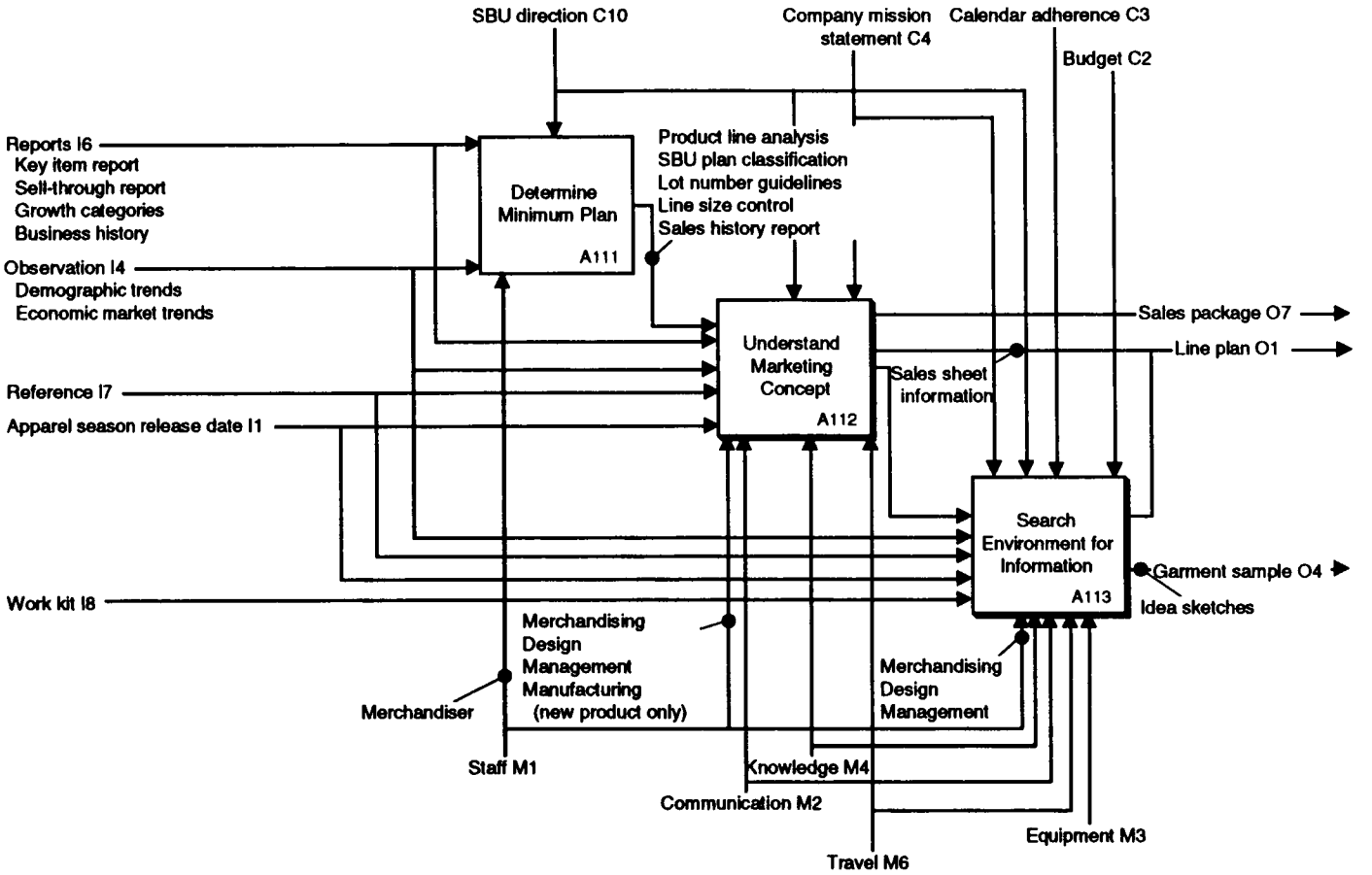
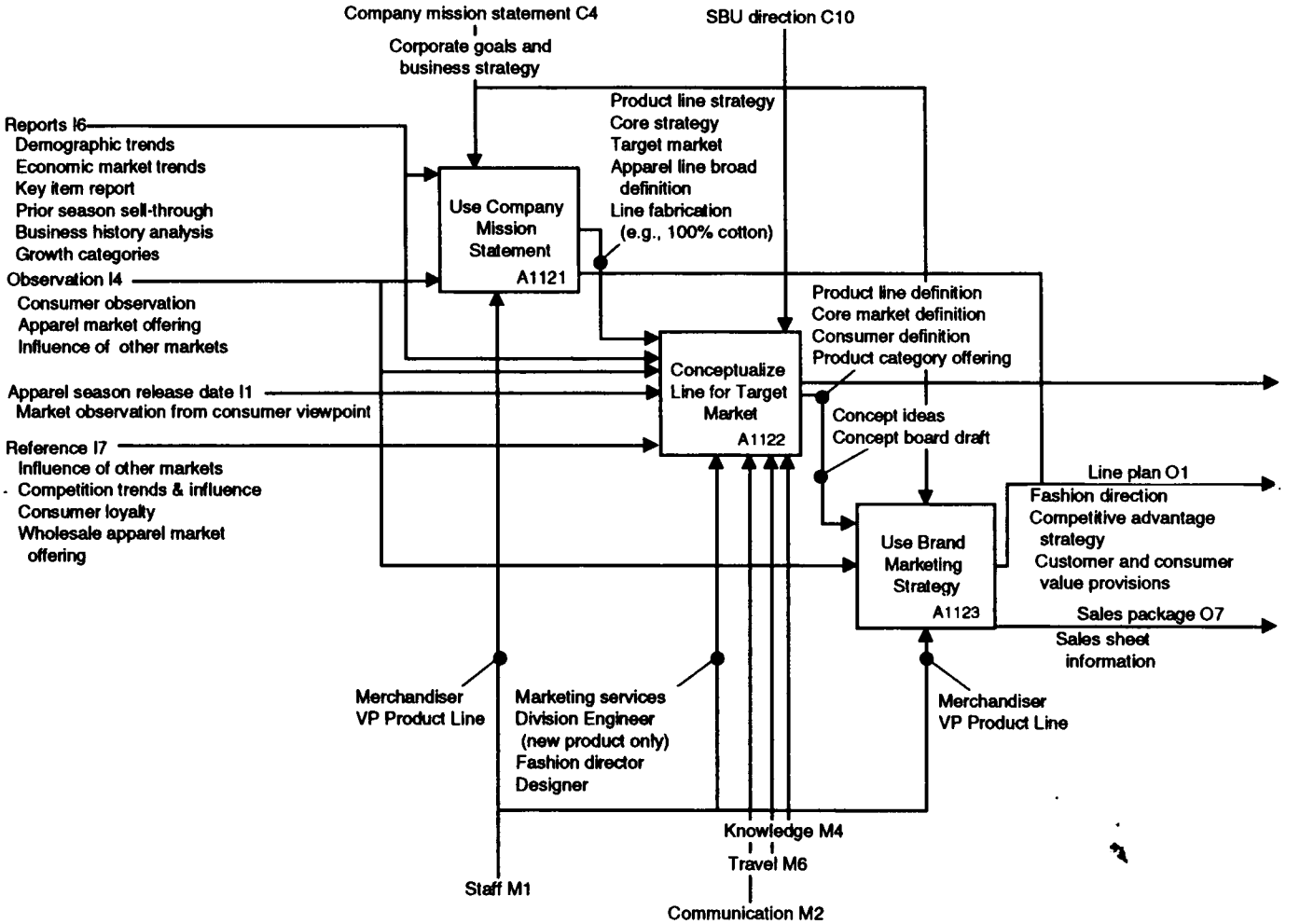


Figure 19. Create apparel line.



NODE: A11

Figure 20. Develop design and business goals.



NODE: A112

Figure 21. Understand marketing concept.

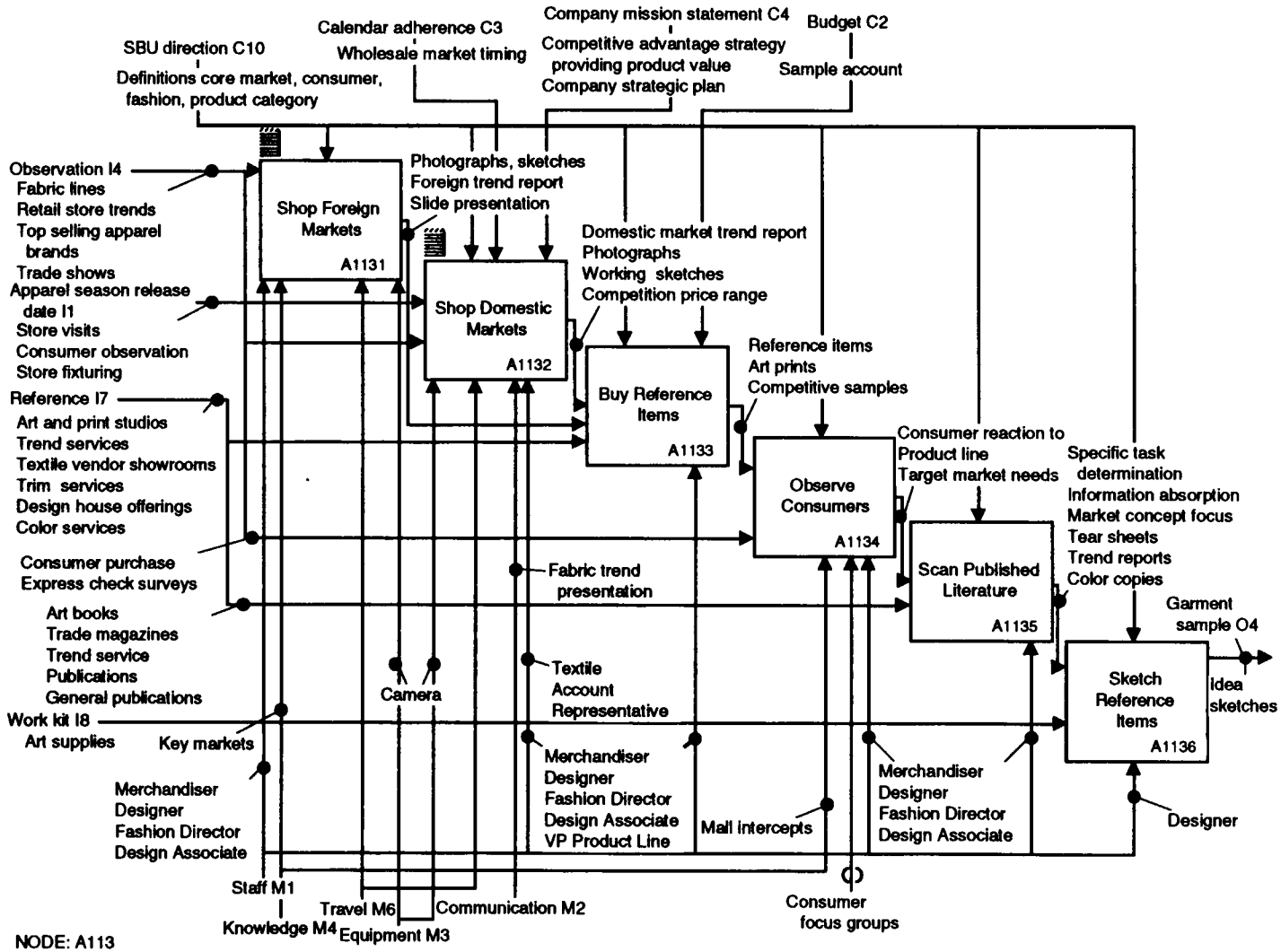


Figure 22. Search environment for information.

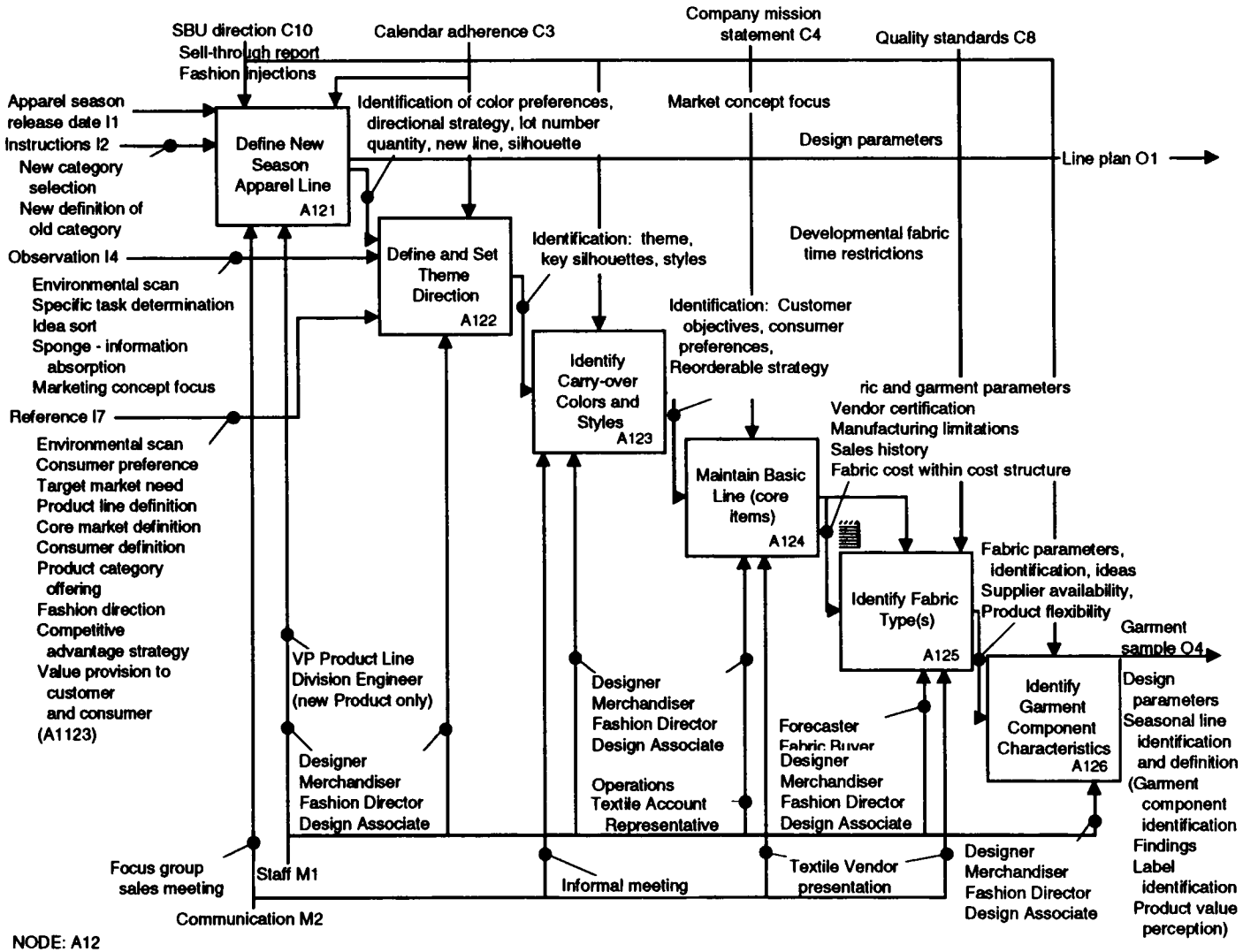


Figure 23. Create design objectives: define problem.

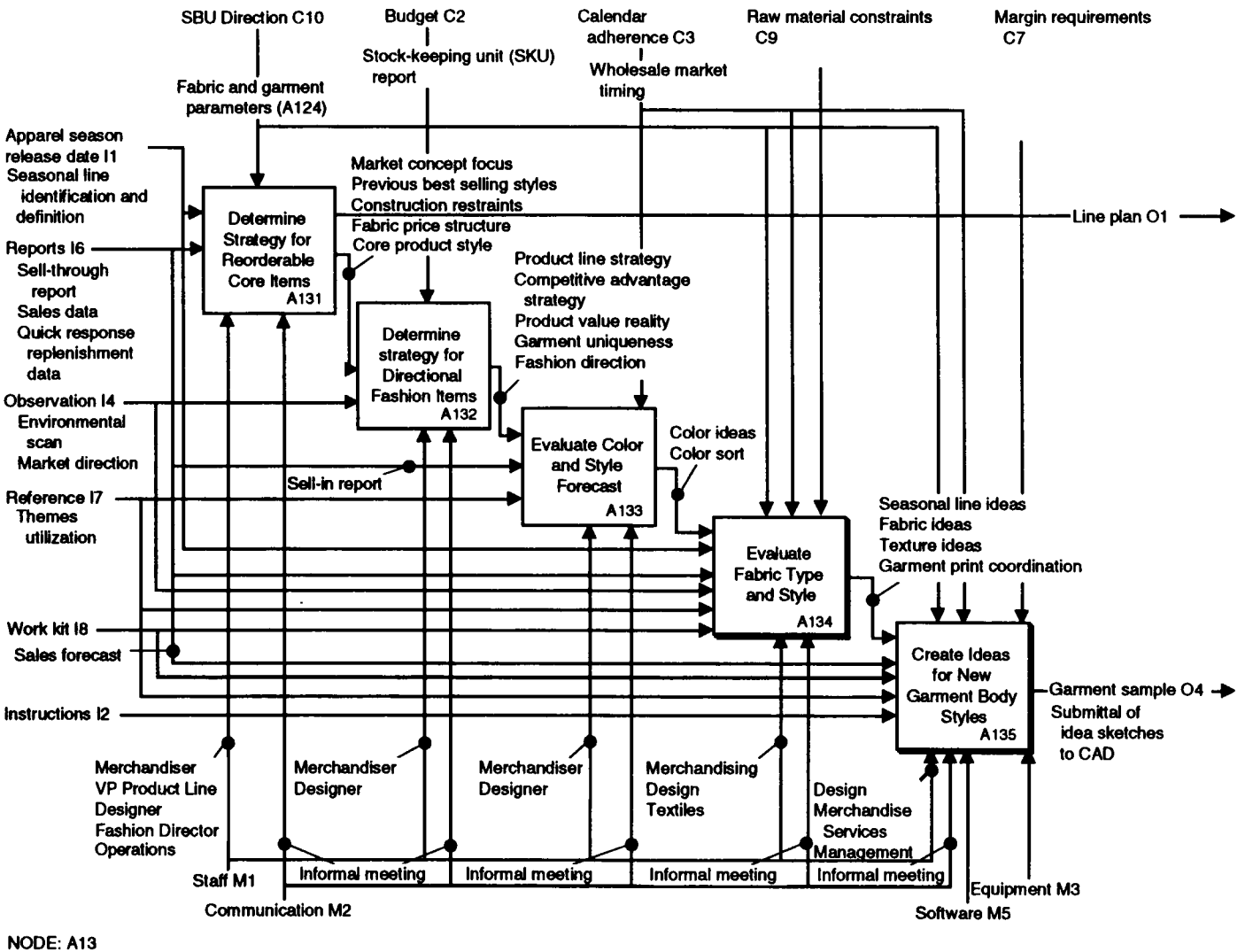
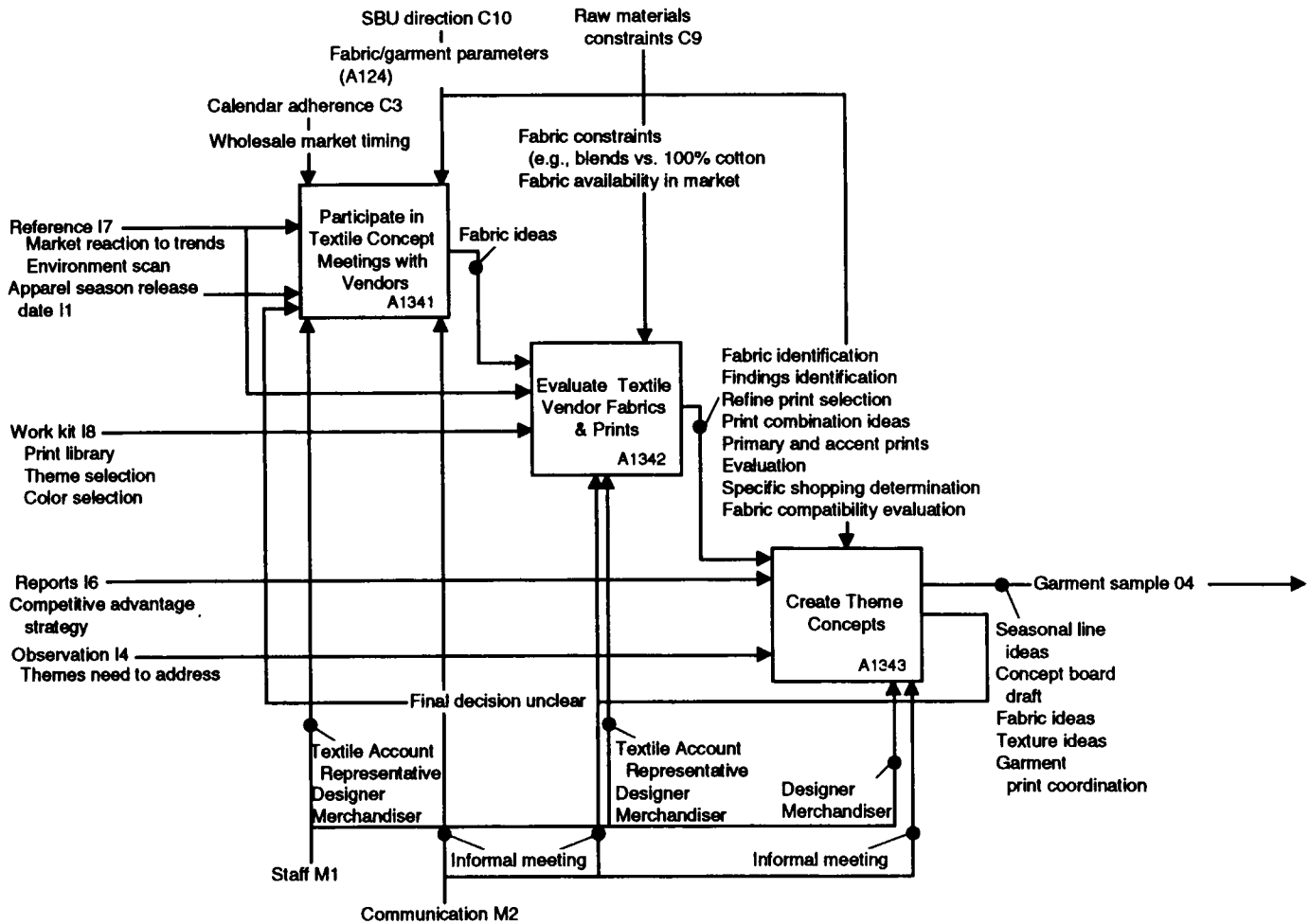
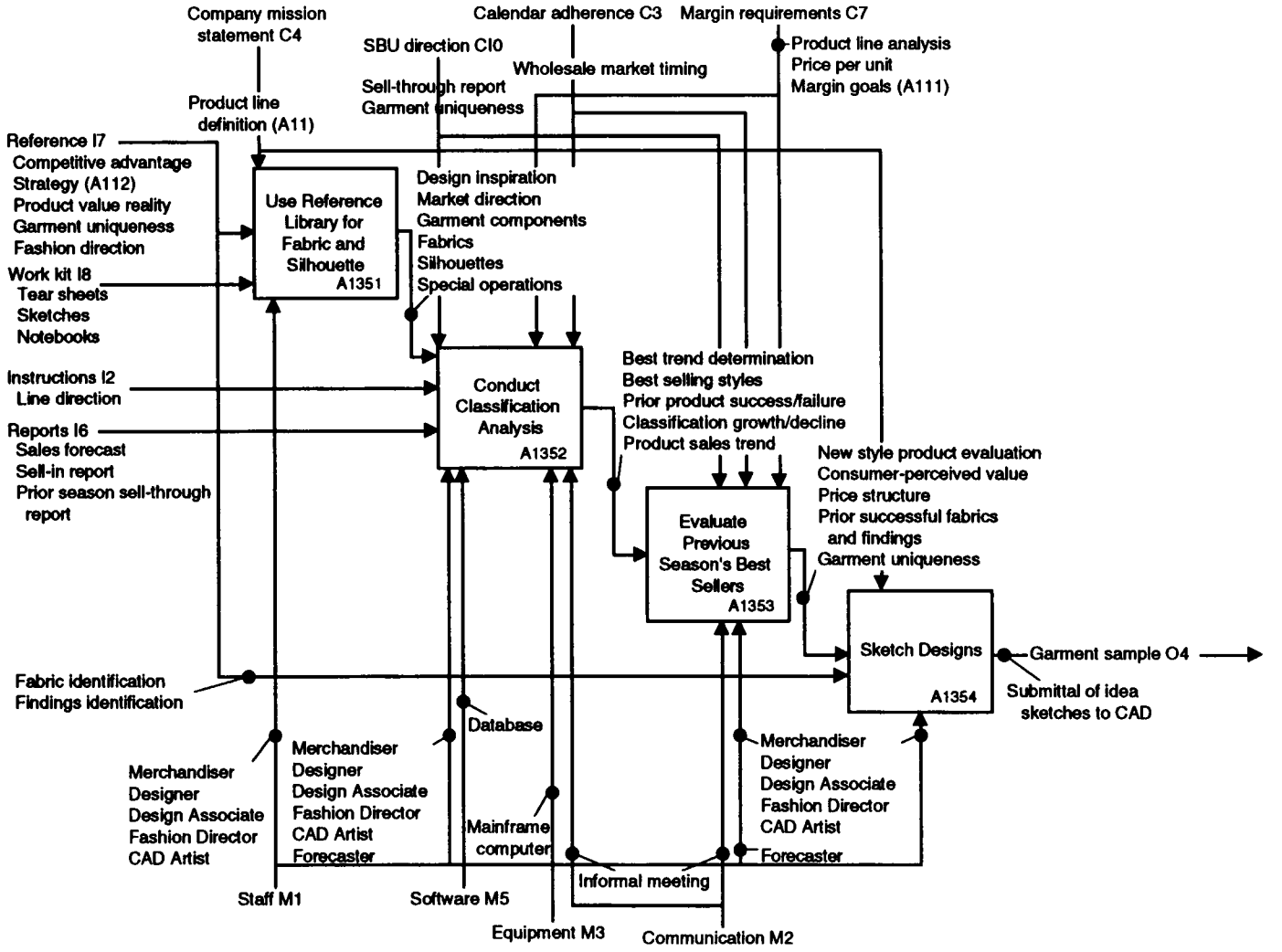


Figure 24. Explore the problem.



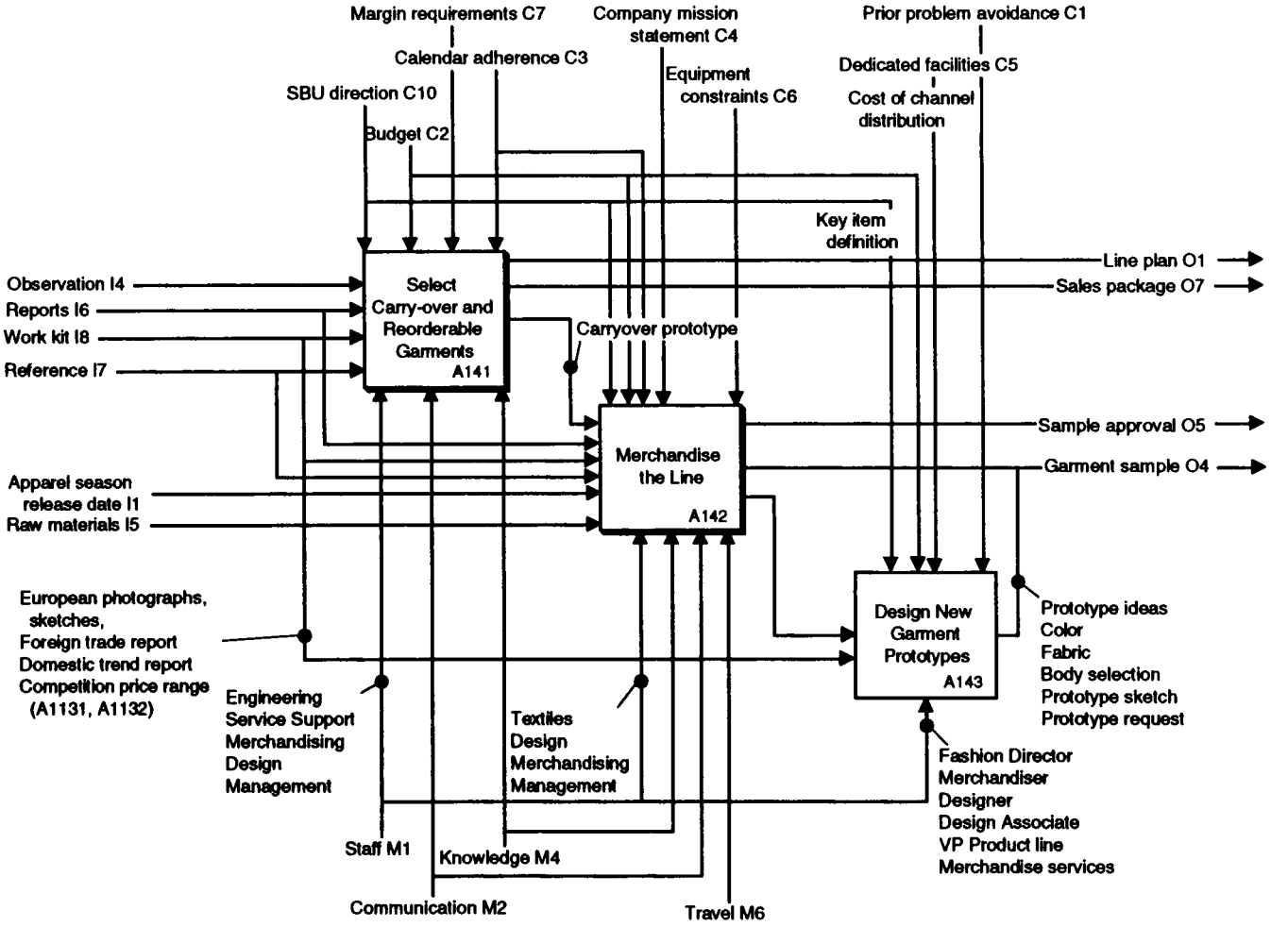
NODE: A134

Figure 25. Evaluate fabric type and style.



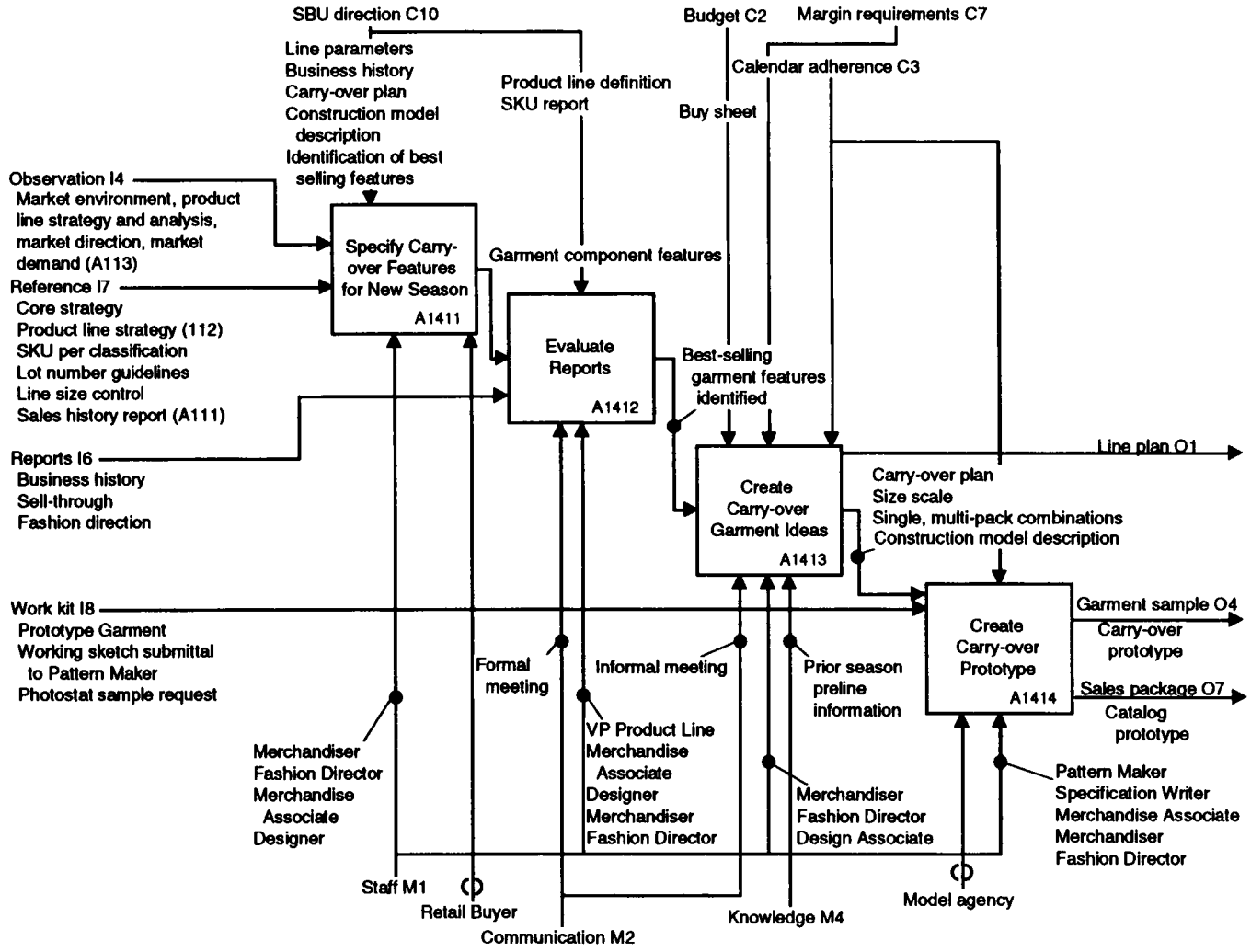
NODE: A135

Figure 26. Create ideas for new garment body styles.



NODE: A14

Figure 27. Search for alternatives.



NODE: A141

Figure 28. Select carry-over and reorderable garments.

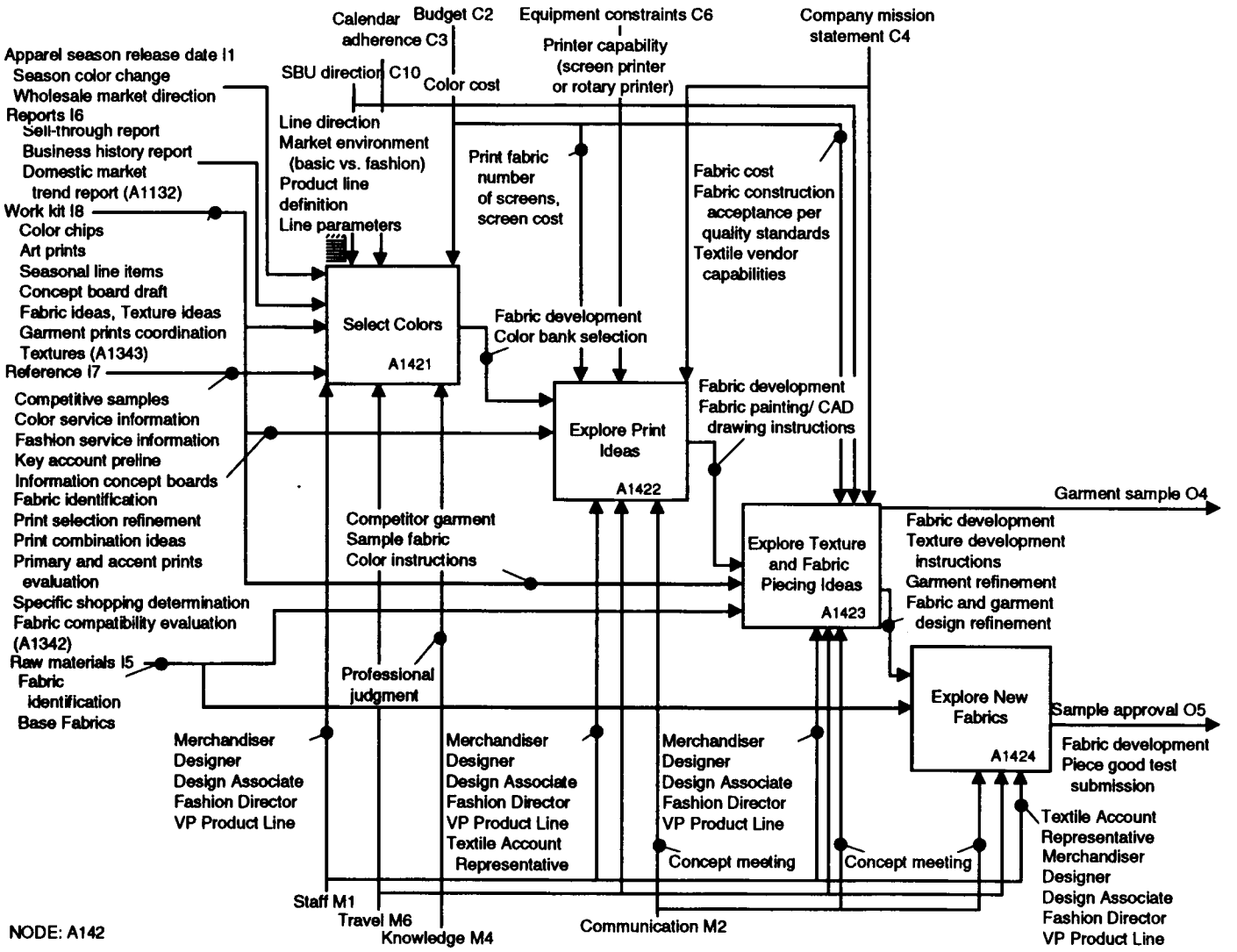


Figure 29. Merchandise the line.

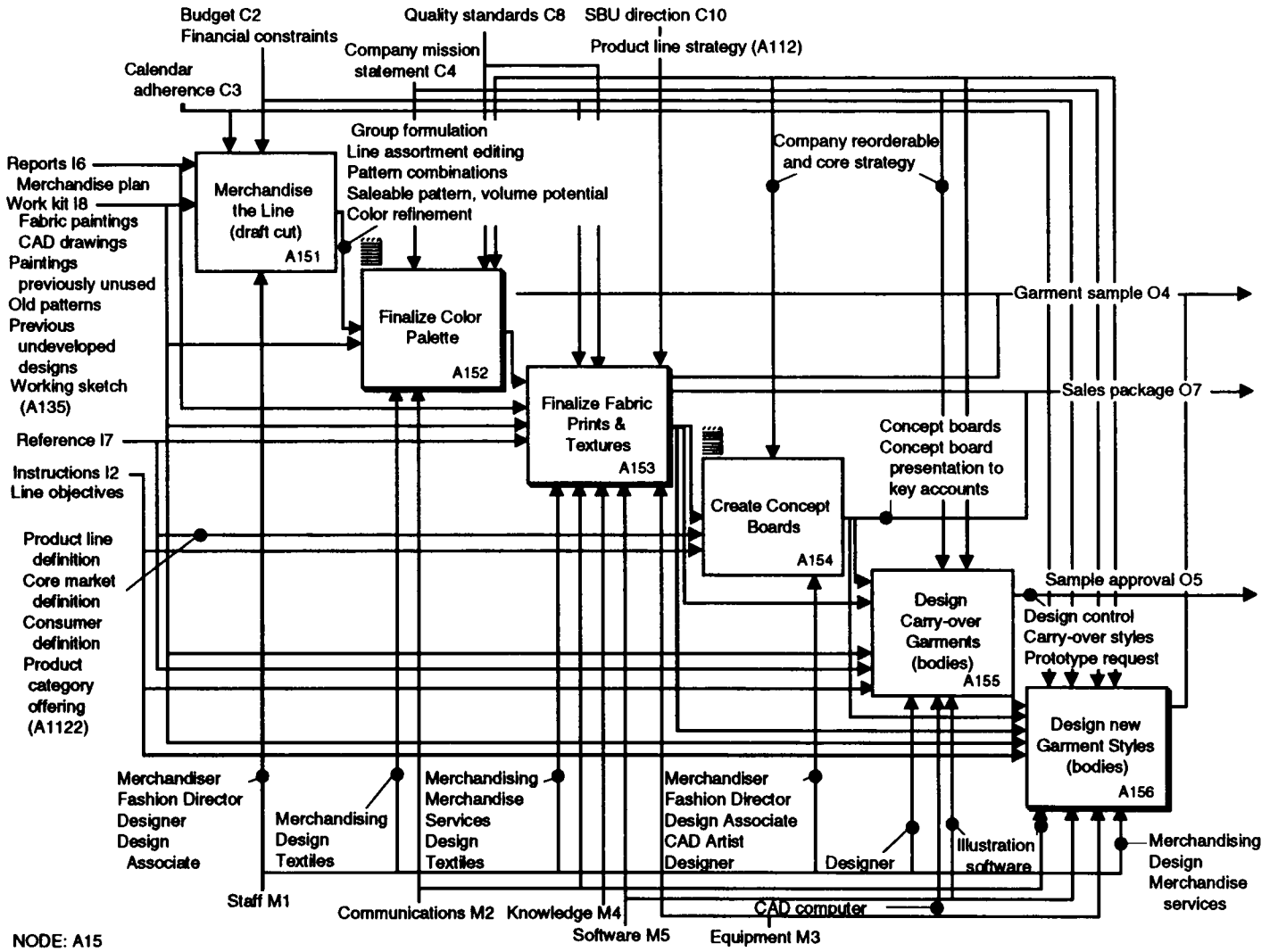
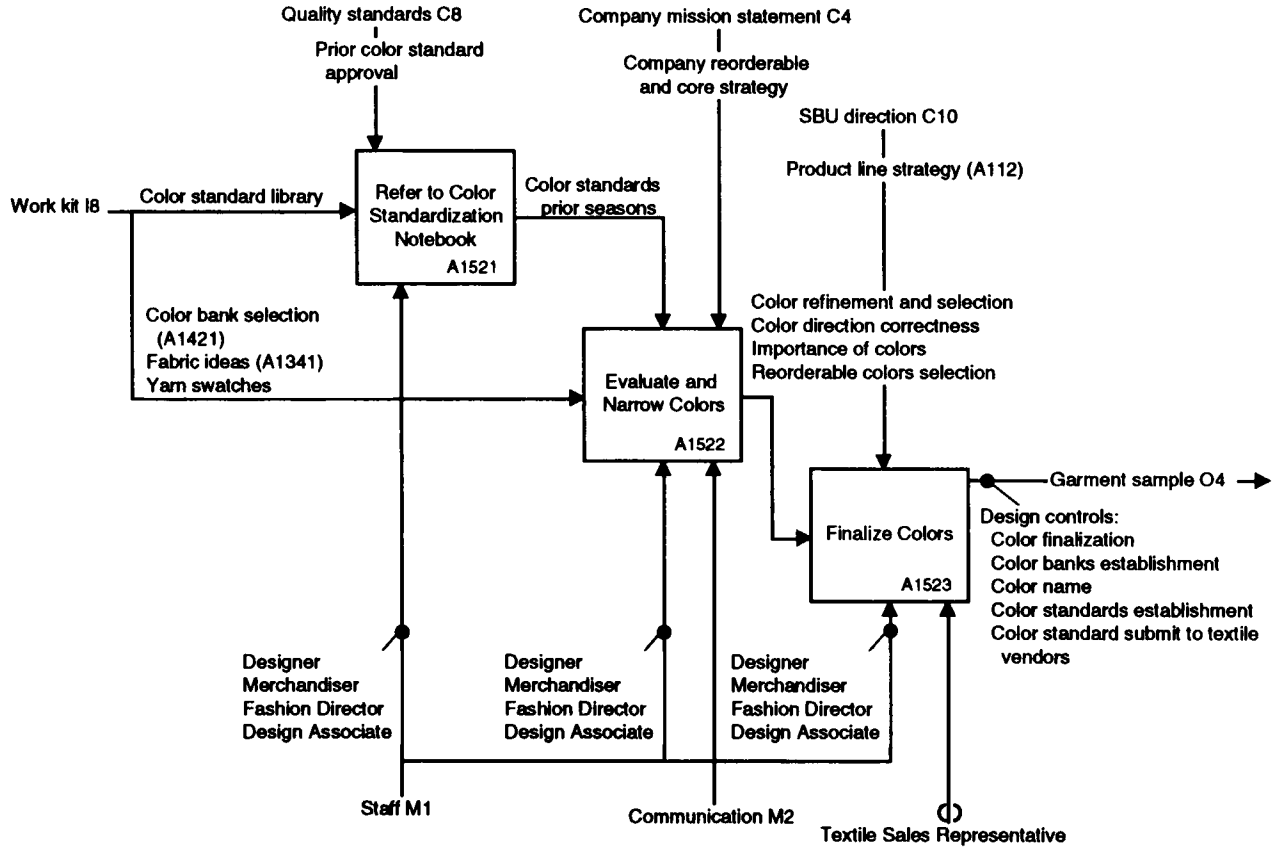
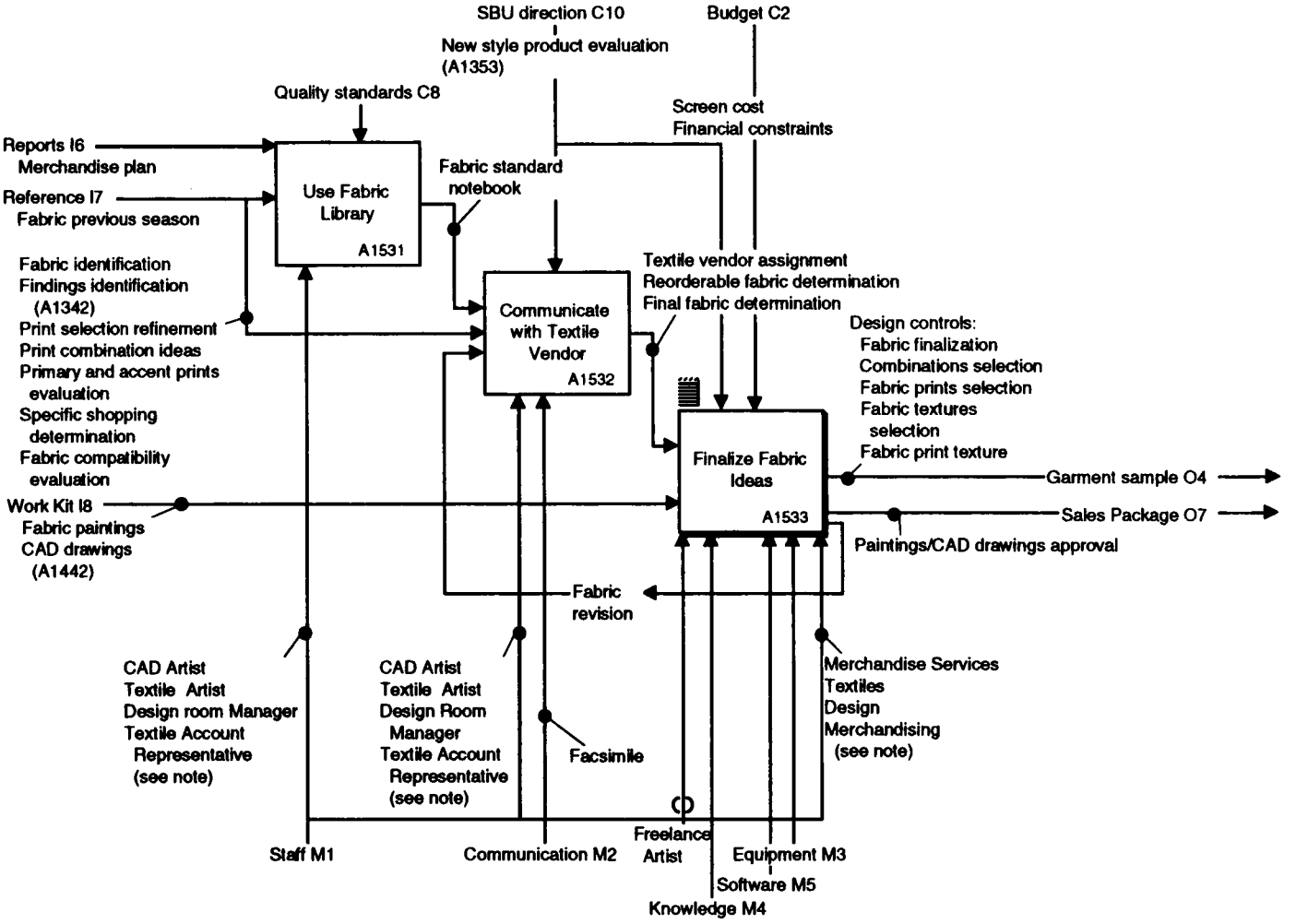


Figure 30. Evaluate and make decisions.



NODE: A152

Figure 31. Finalize color palette.



NODE: A153

Figure 32. Finalize fabric prints and textures.

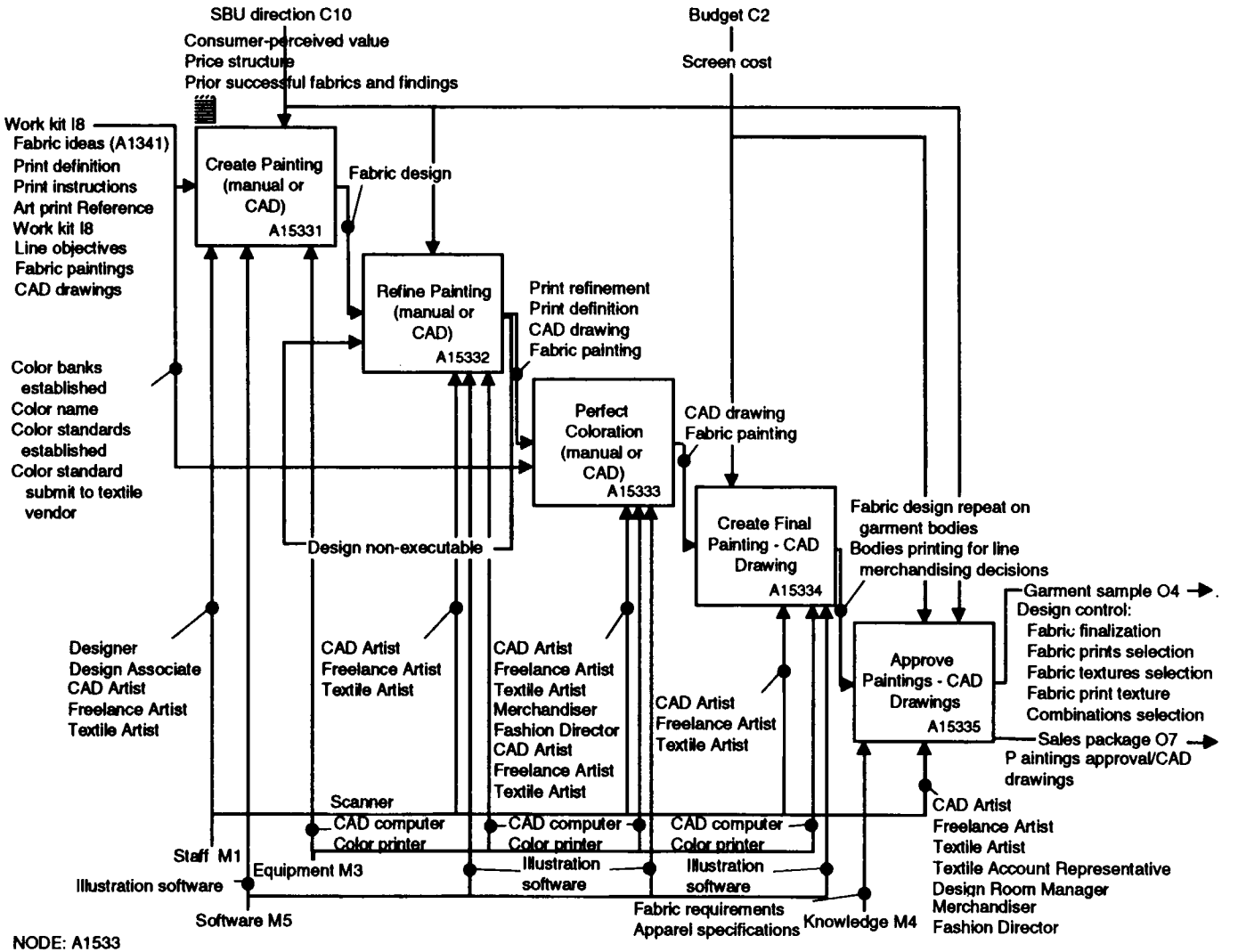
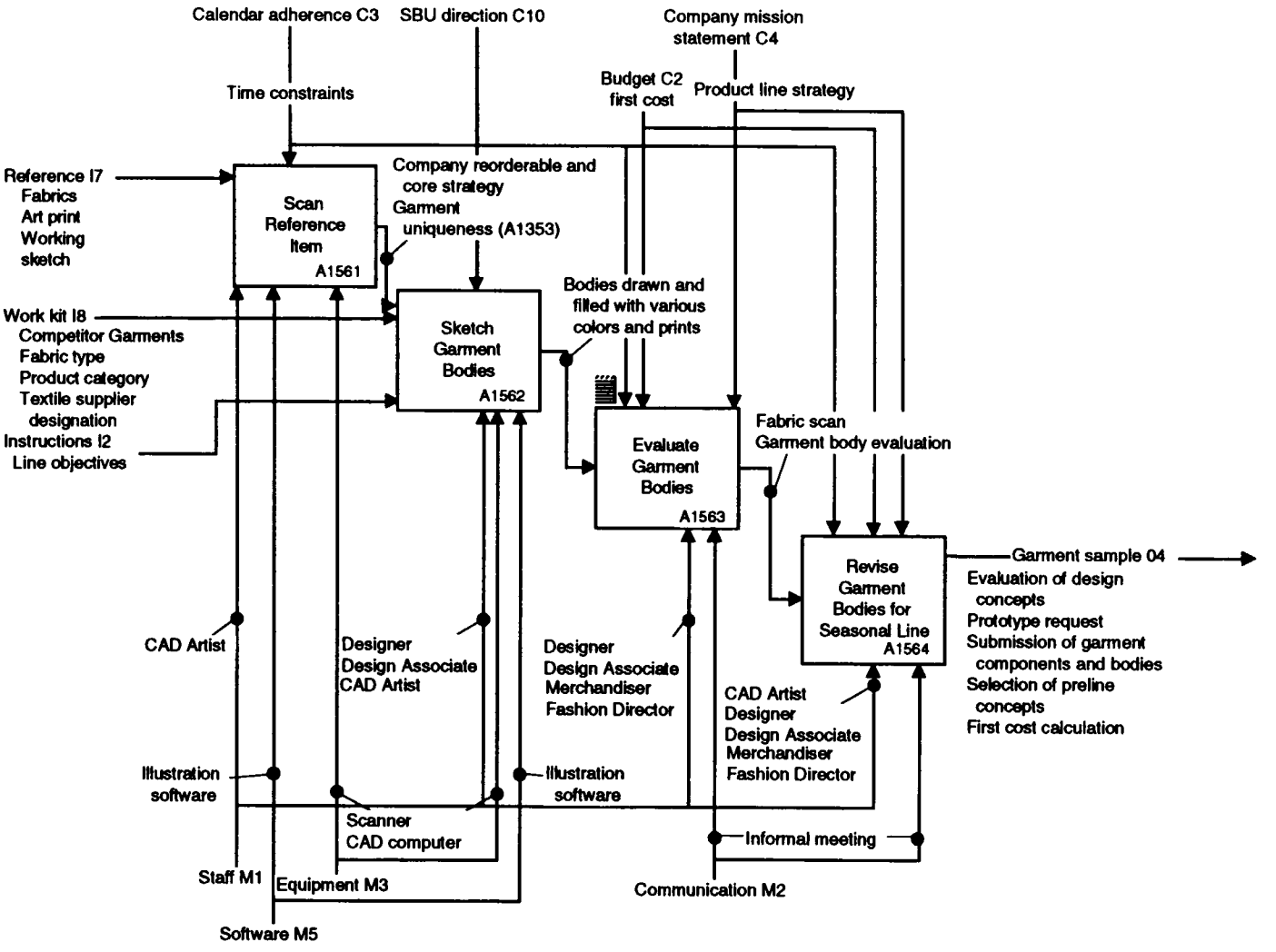


Figure 33. Finalize fabric ideas.



NODE: A156

Figure 34. Design new garment styles (bodies).

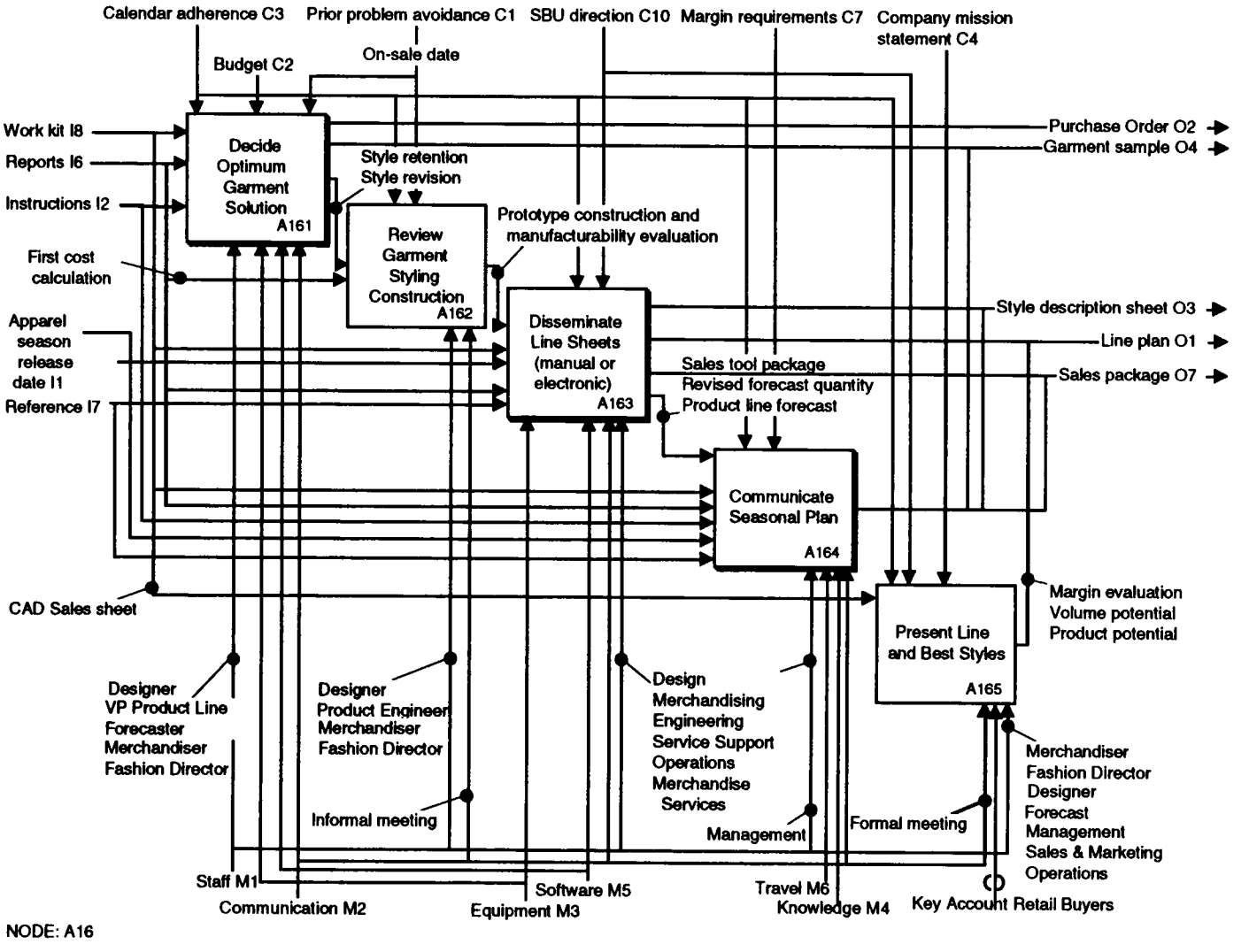


Figure 35. Specify and communicate solution.

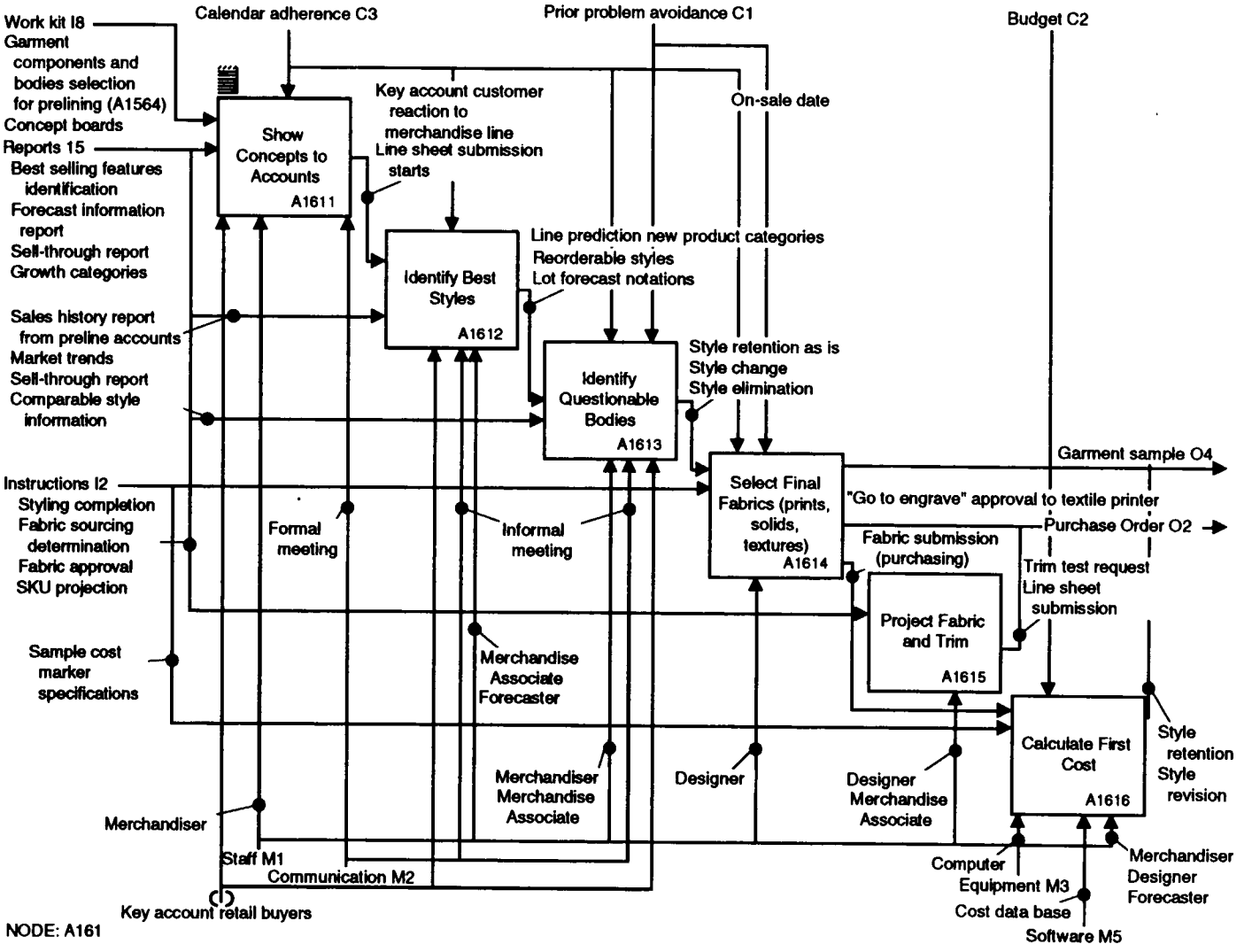


Figure 36. Decide optimum garment solution.

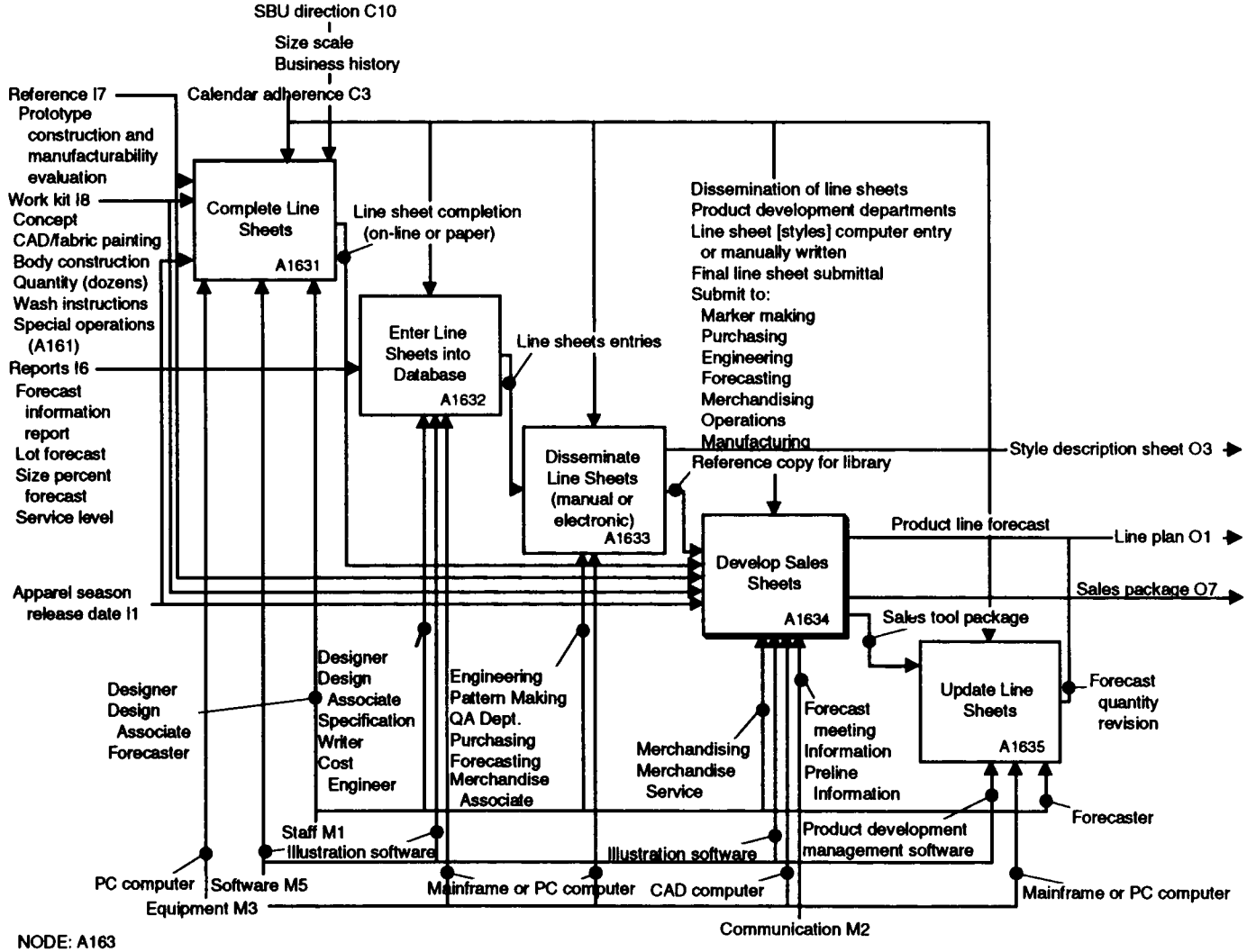
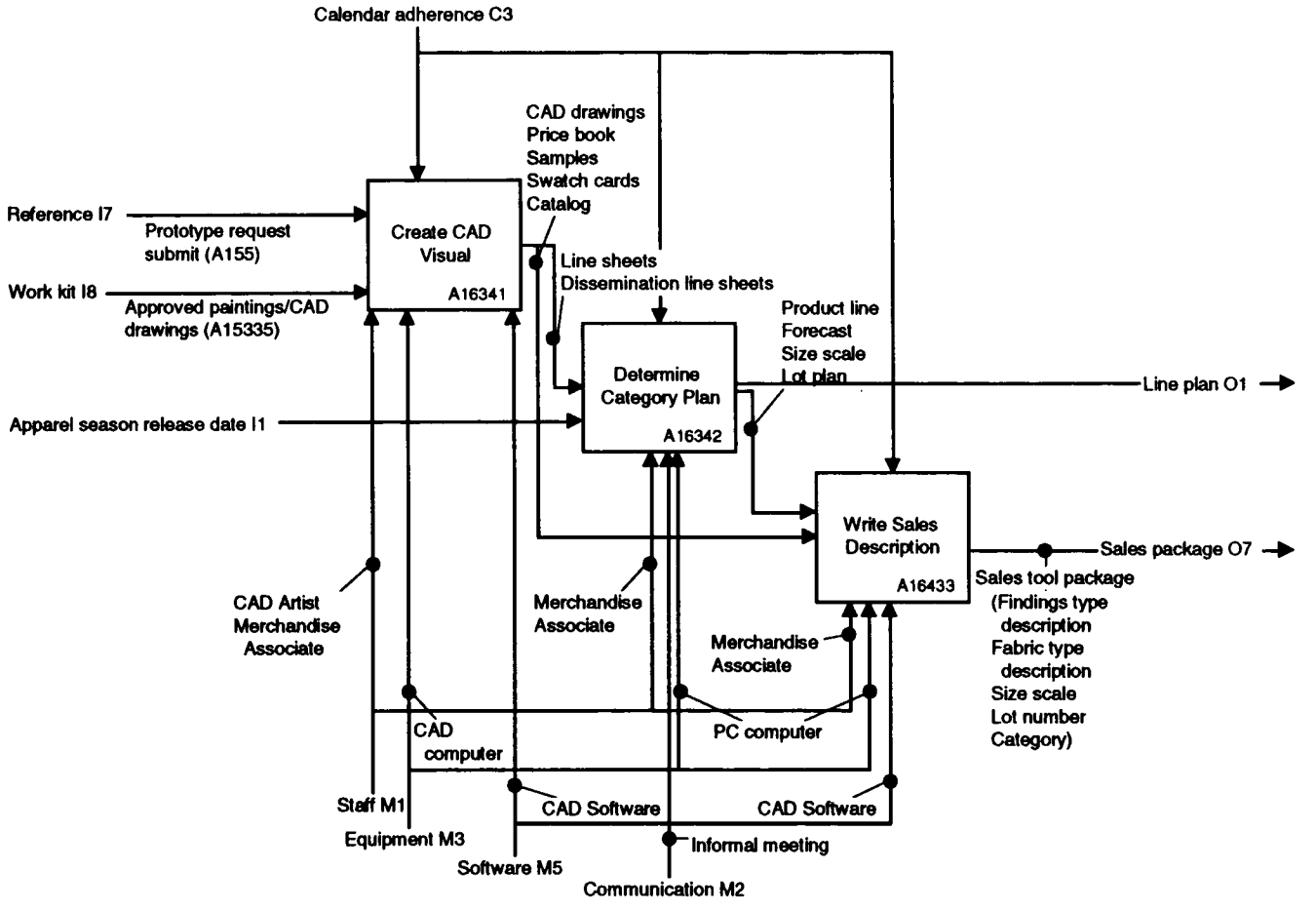
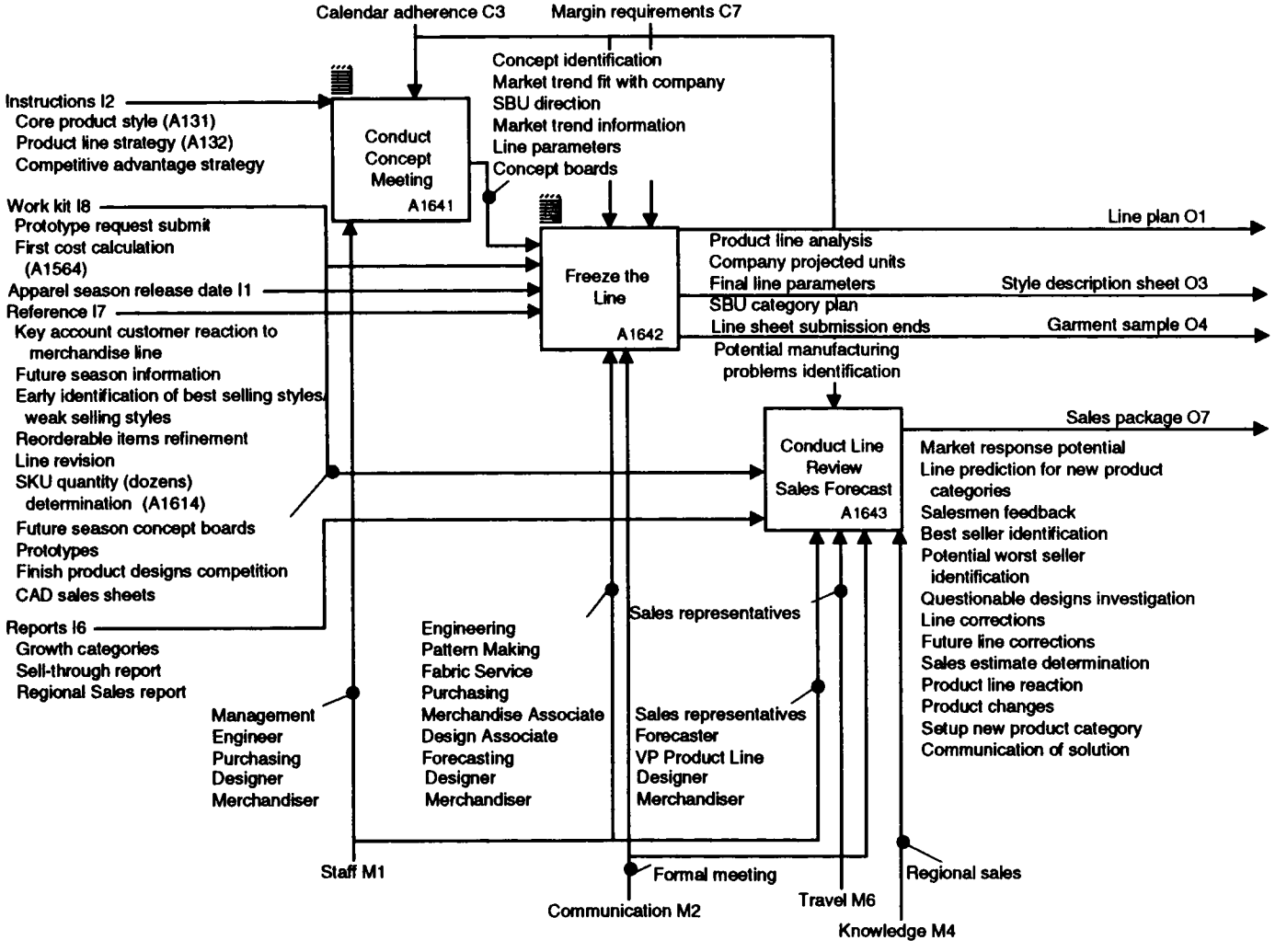


Figure 37. Disseminate line sheets (manual or electronic).



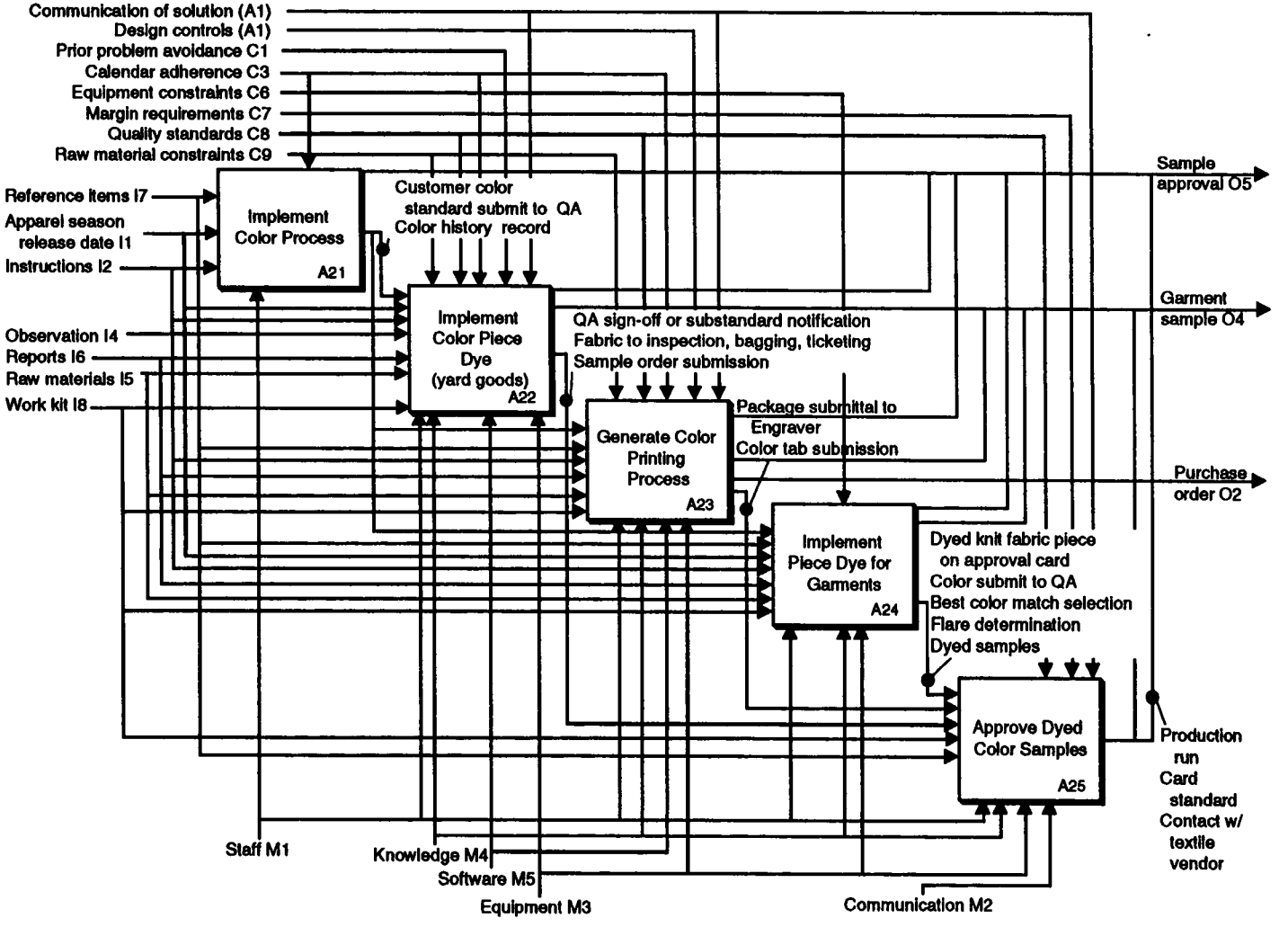
NODE: A1634

Figure 38. Develop sales sheets.



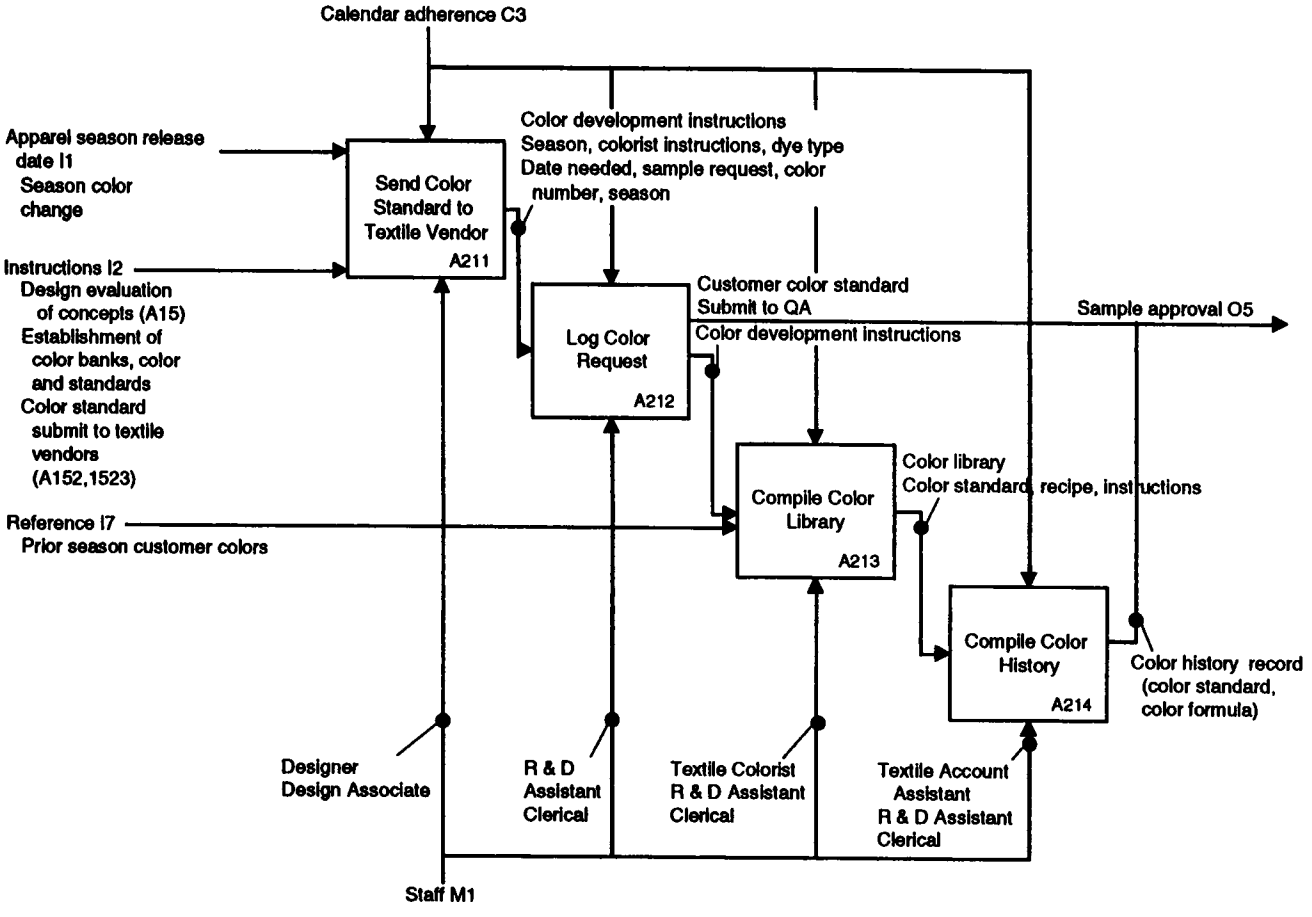
NODE: A164

Figure 39. Communicate seasonal plan.



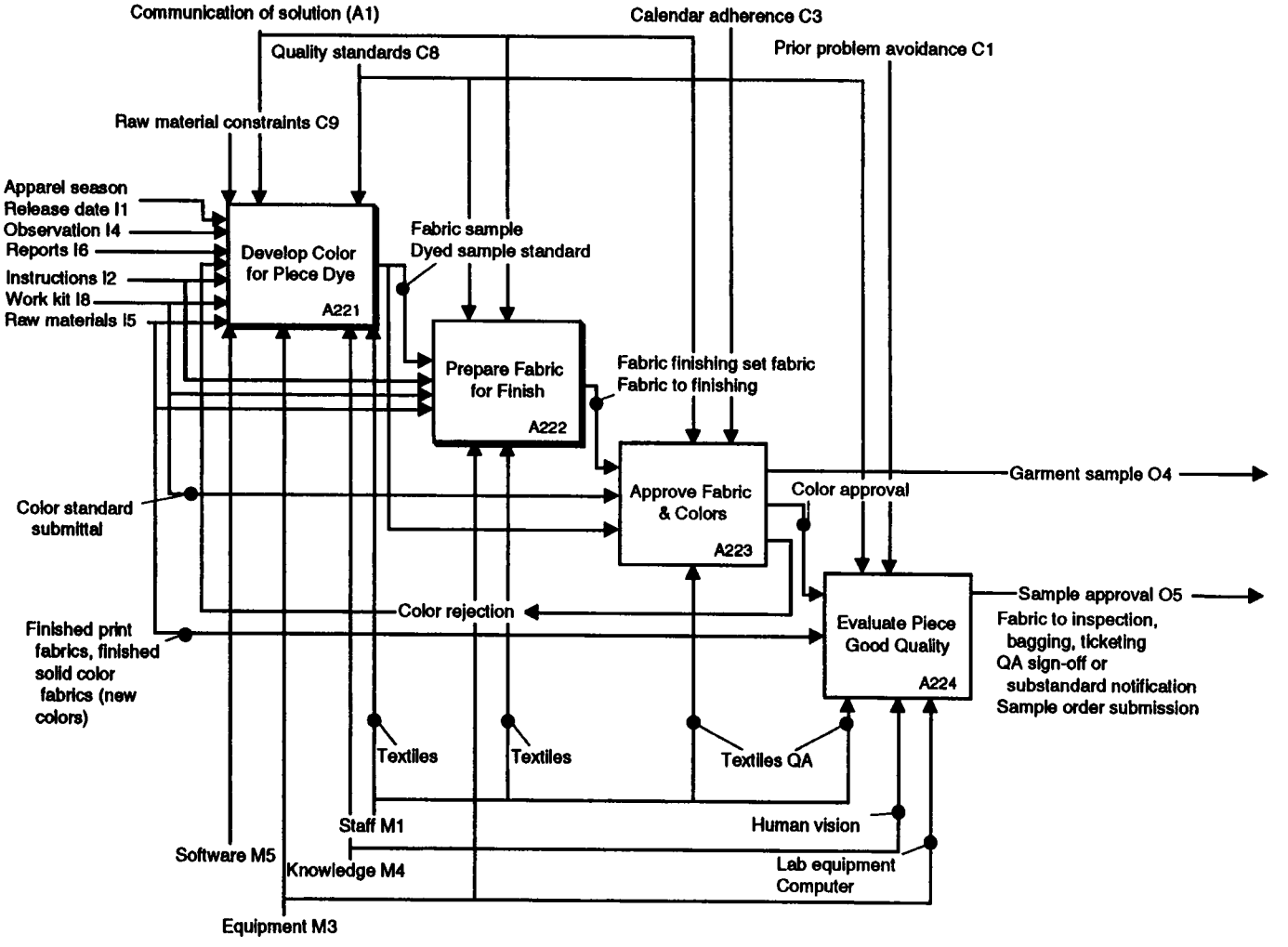
NODE: A2

Figure 40. Develop colors and prints.



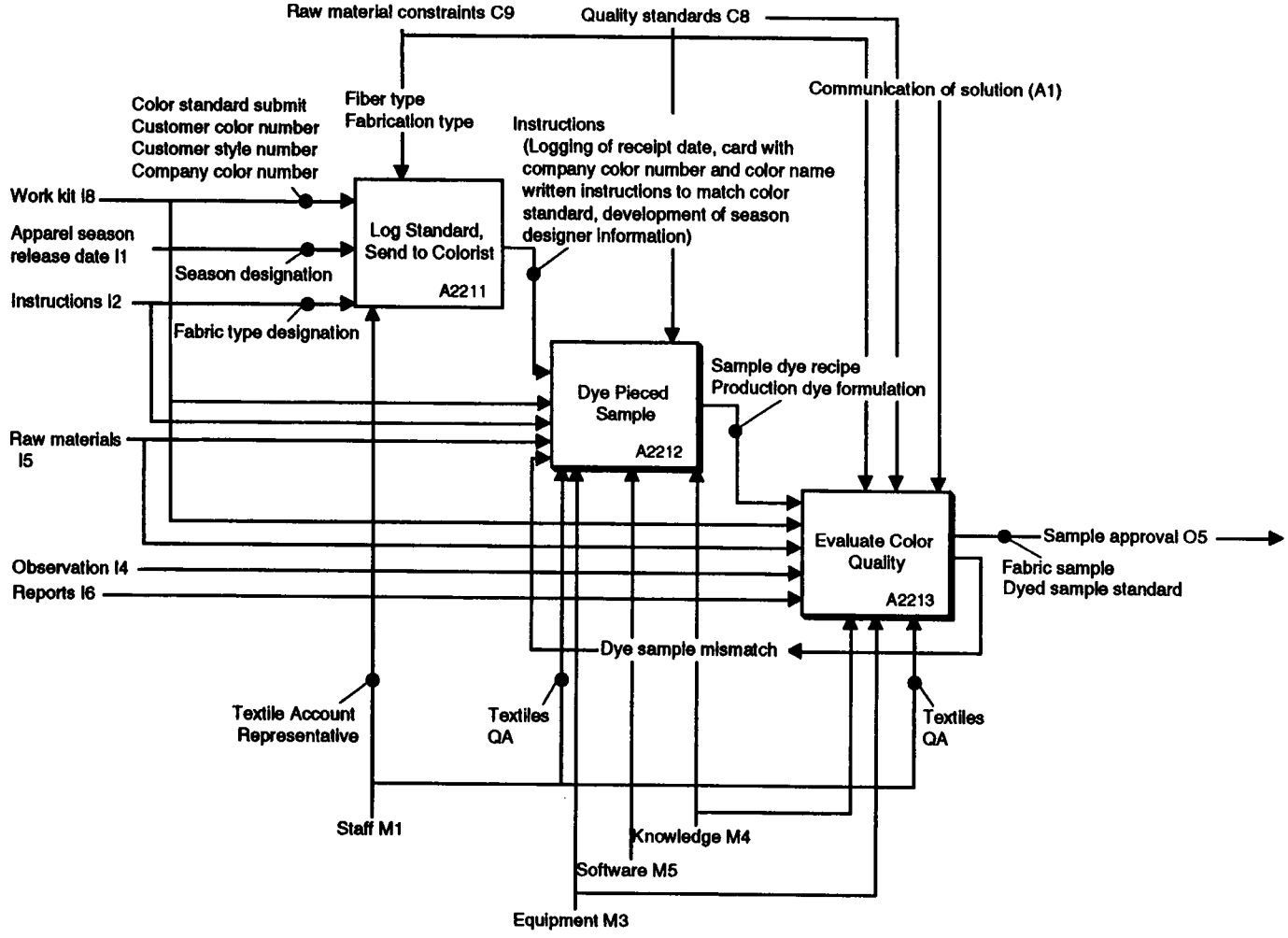
NODE: A21

Figure 41. Implement color process.



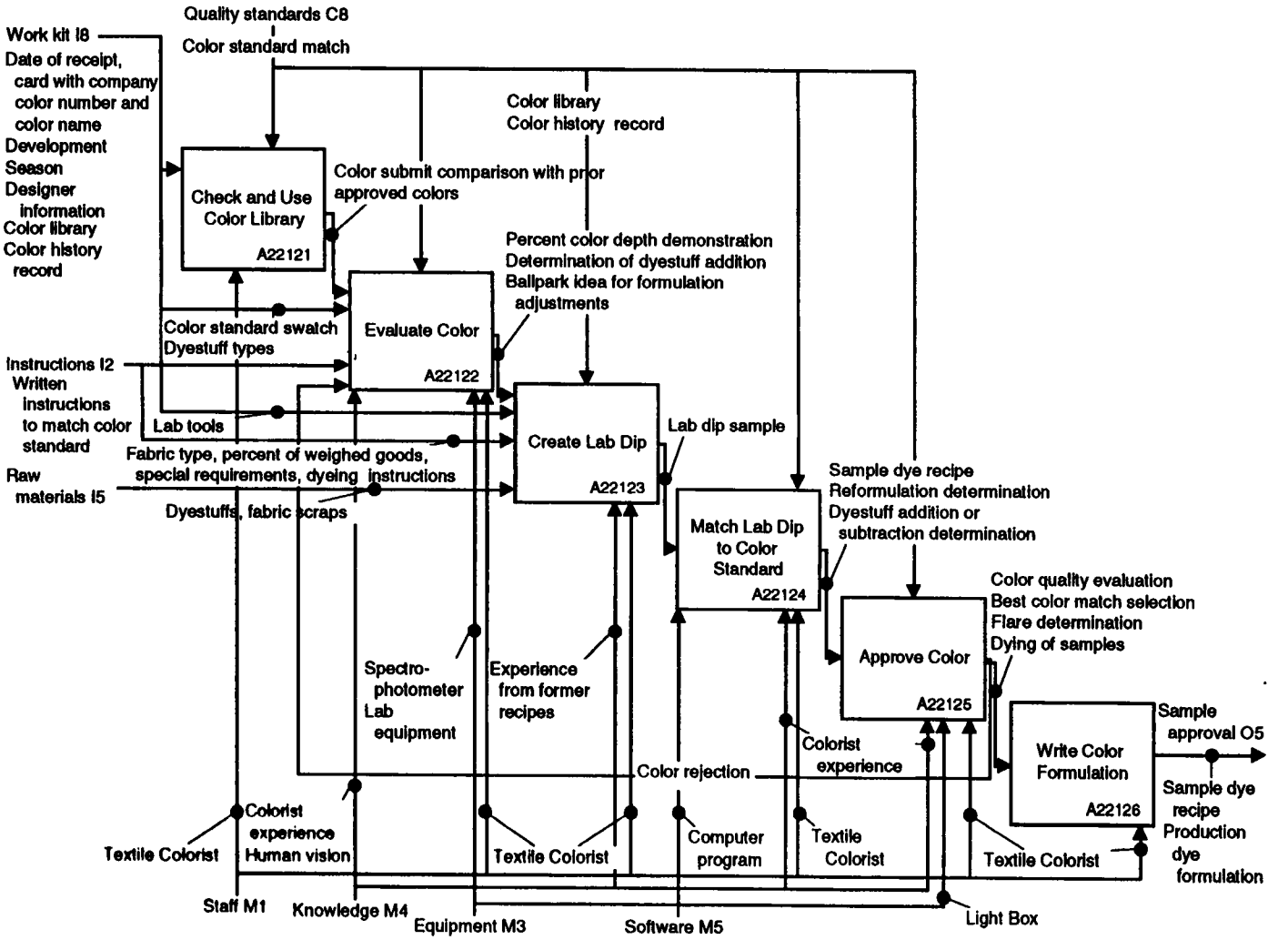
NODE: A22

Figure 42. Implement color piece dye (yard goods).



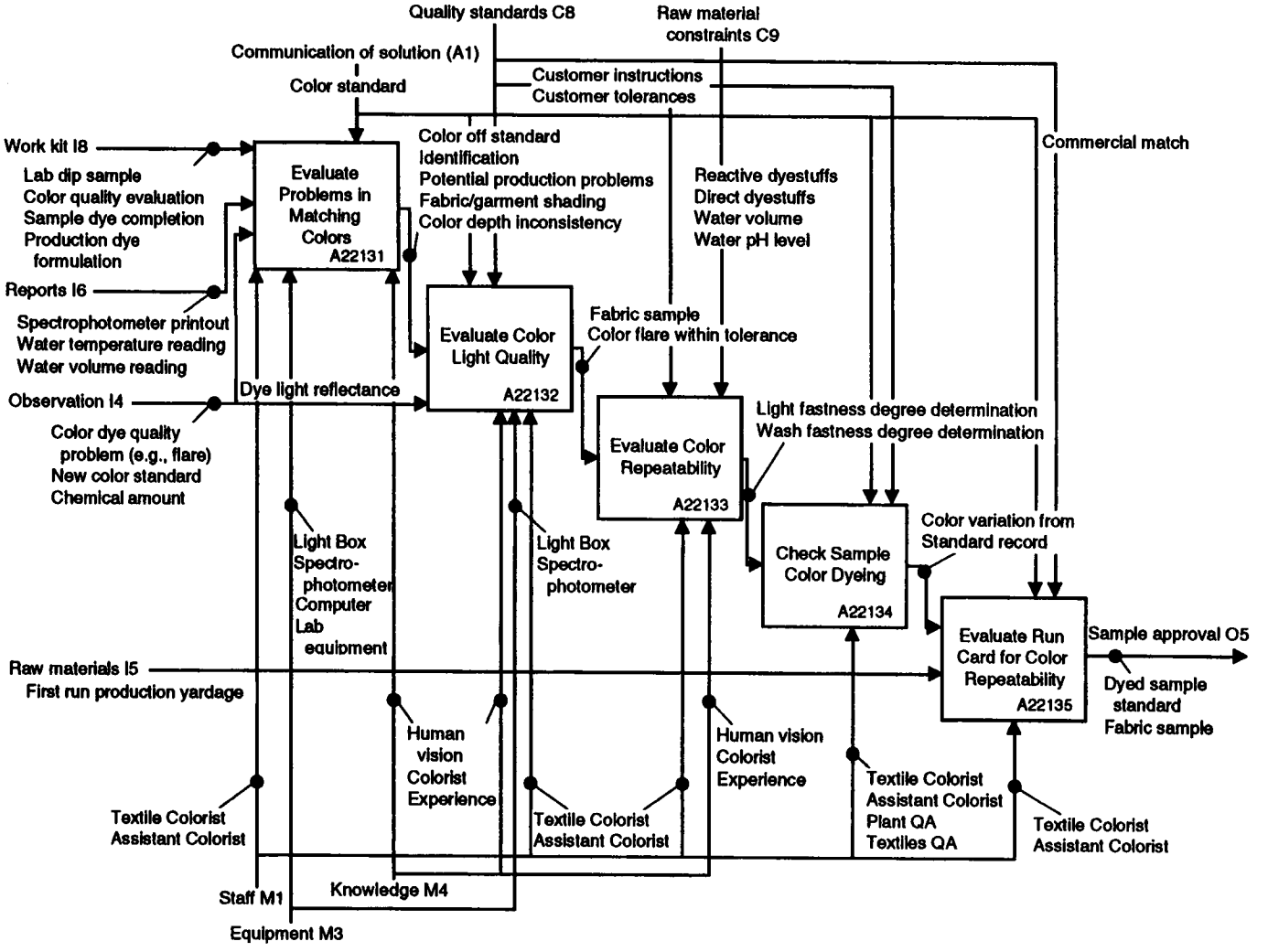
NODE: A221

Figure 43. Develop color for piece dye.



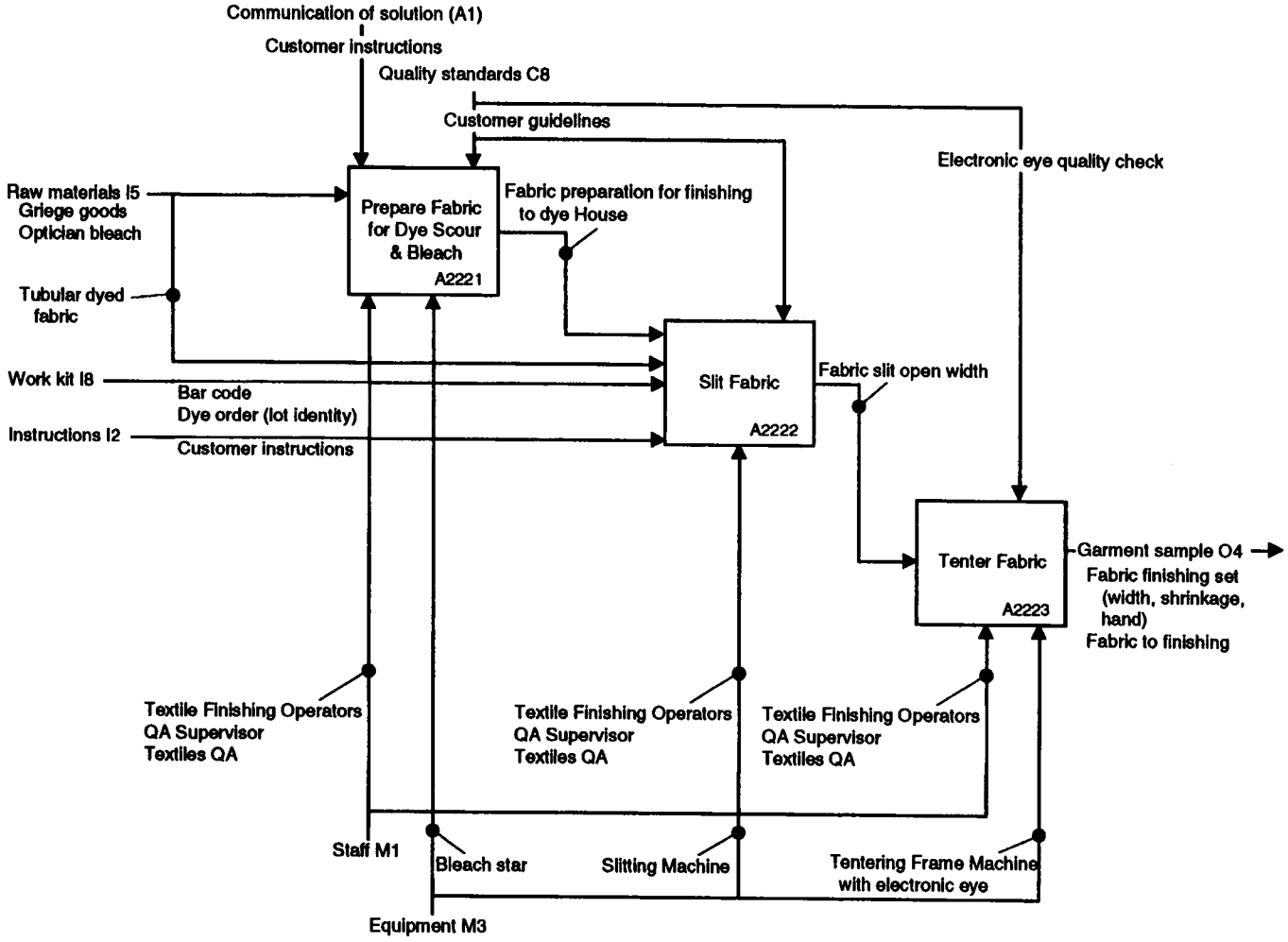
NODE: A 2212

Figure 44. Dye pieced sample.



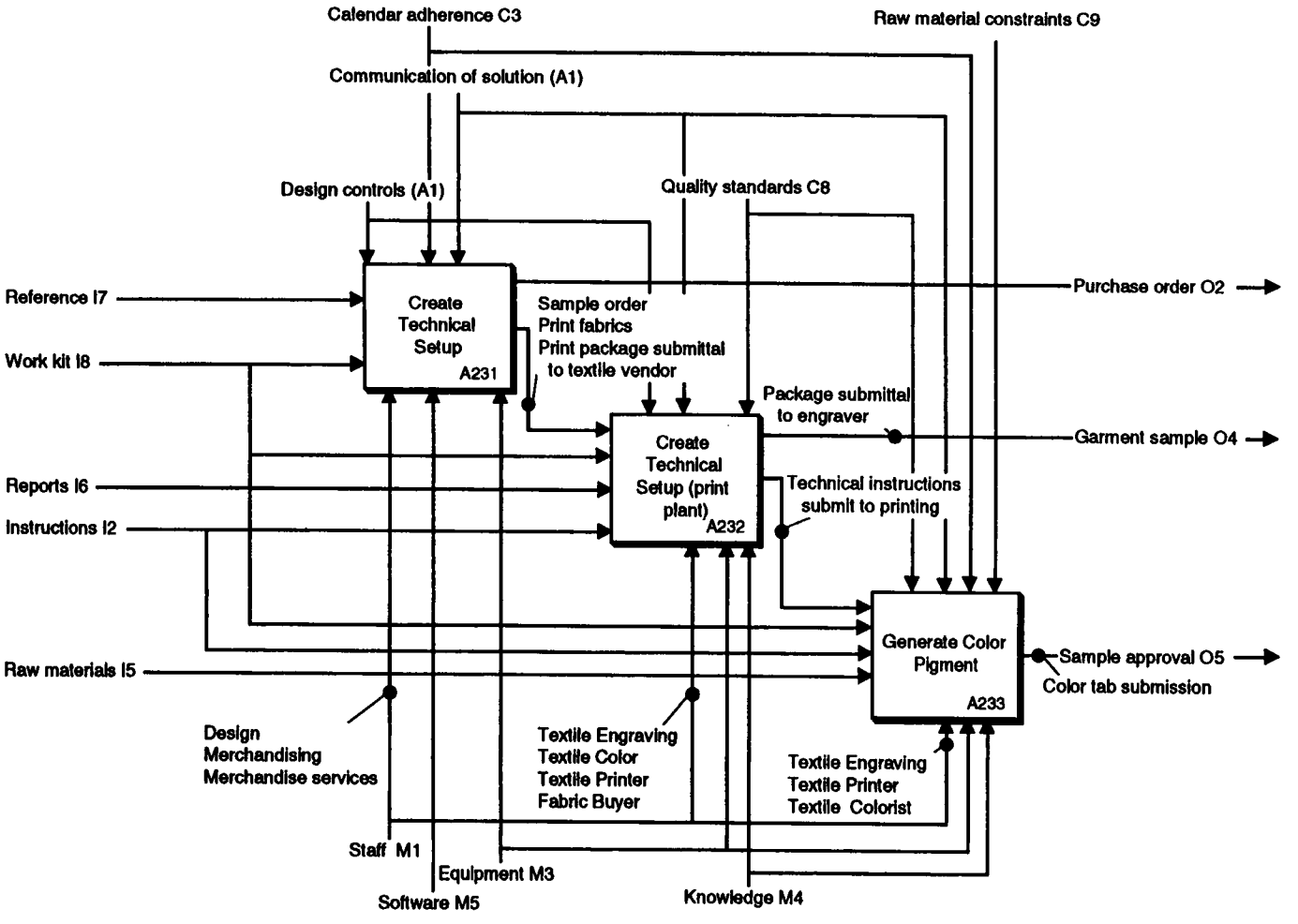
NODE: A2213

Figure 45. Evaluate color quality.



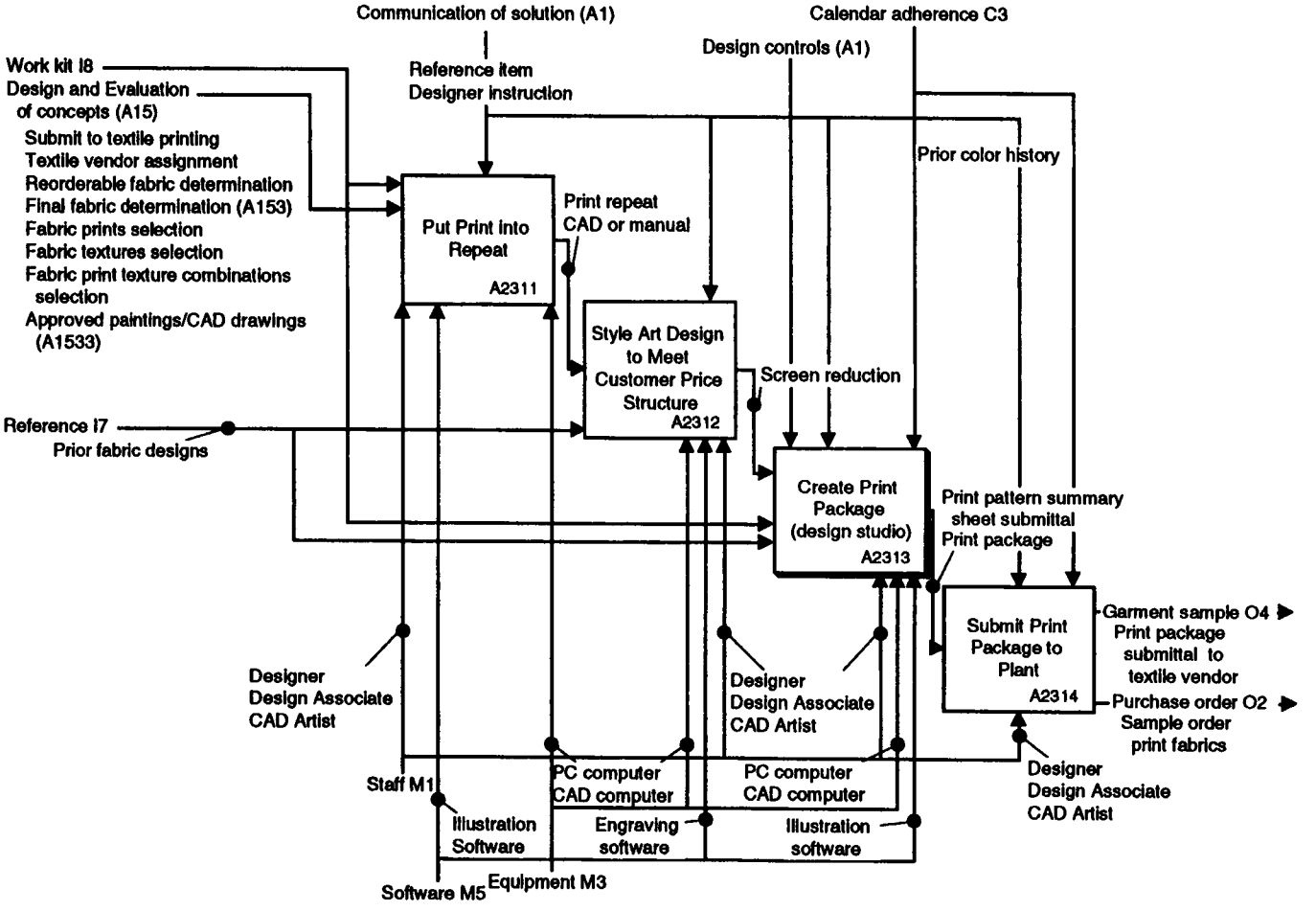
NODE: A222

Figure 46. Prepare fabric for finish.



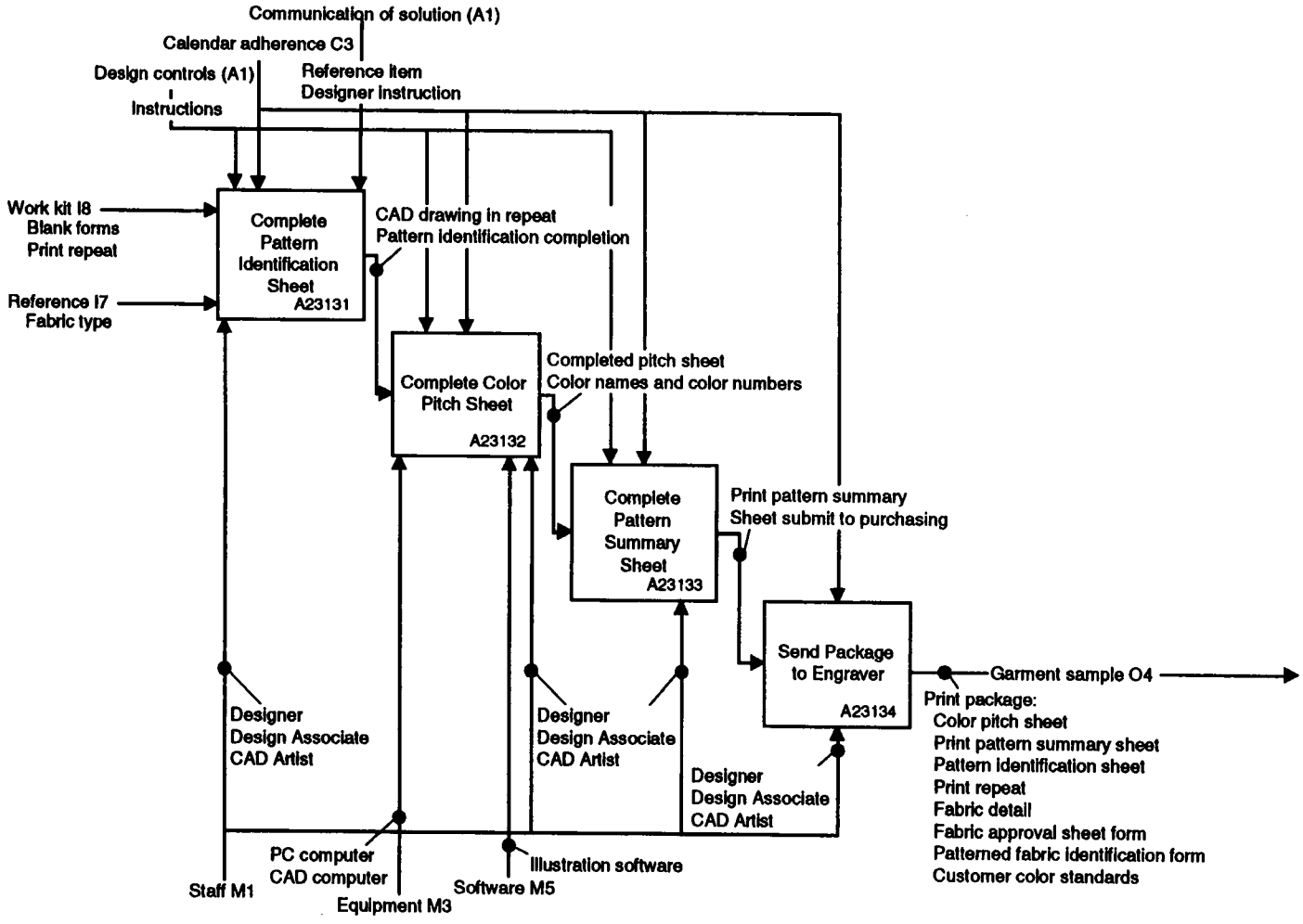
NODE: A23

Figure 47. Generate color printing process.



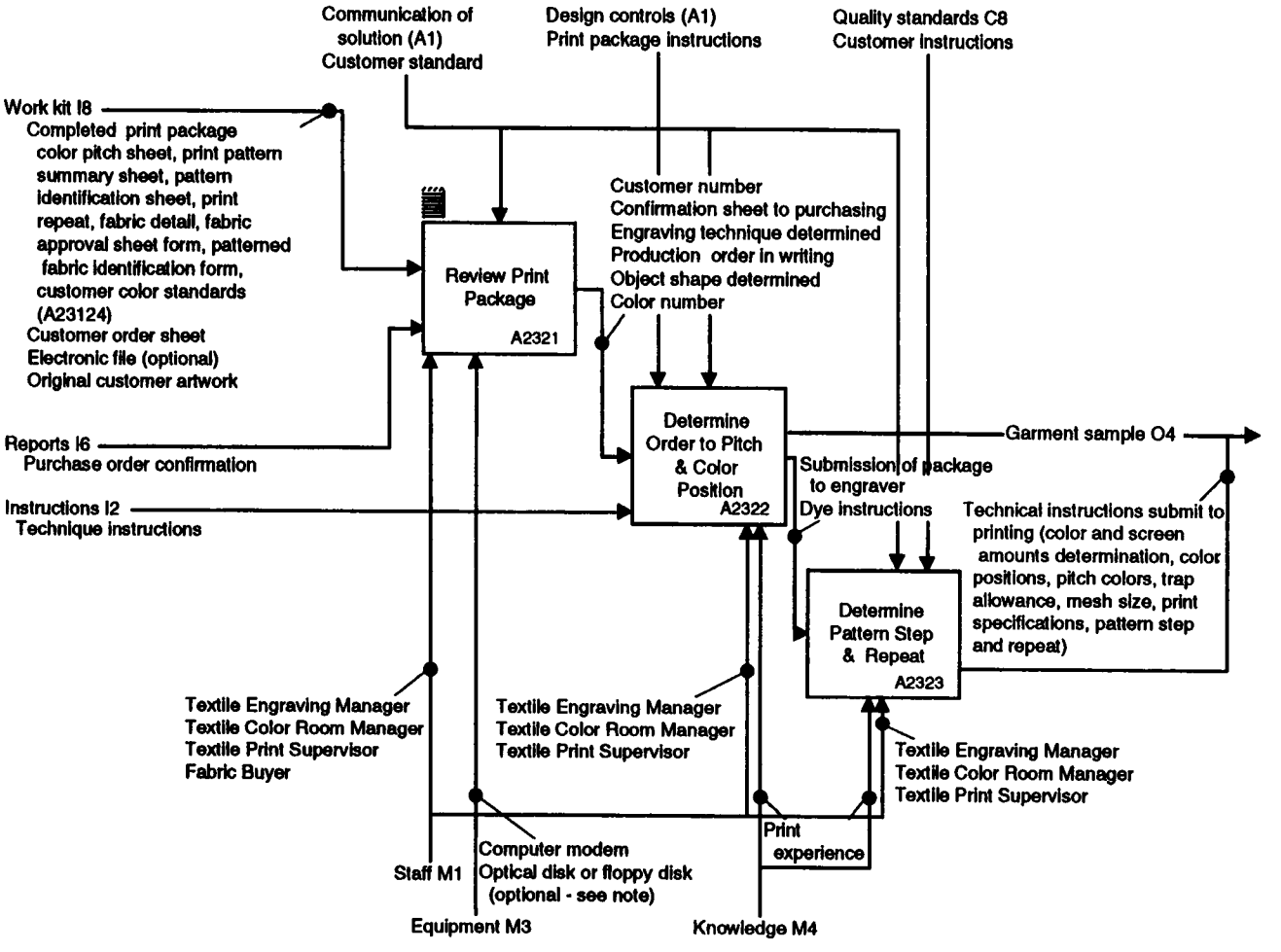
NODE: A231

Figure 48. Create technical setup.



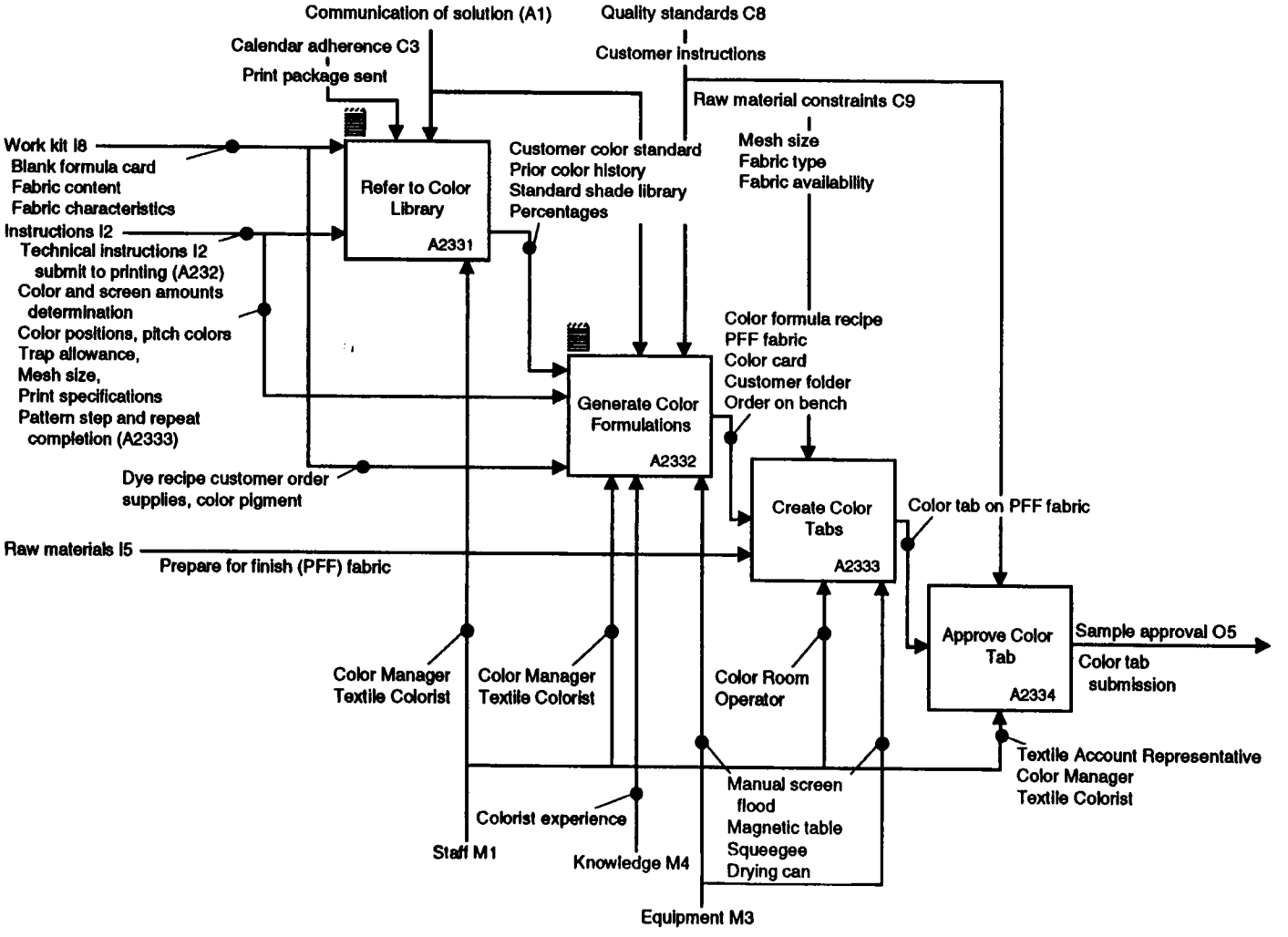
NODE: A2313

Figure 49. Create print package (design studio).



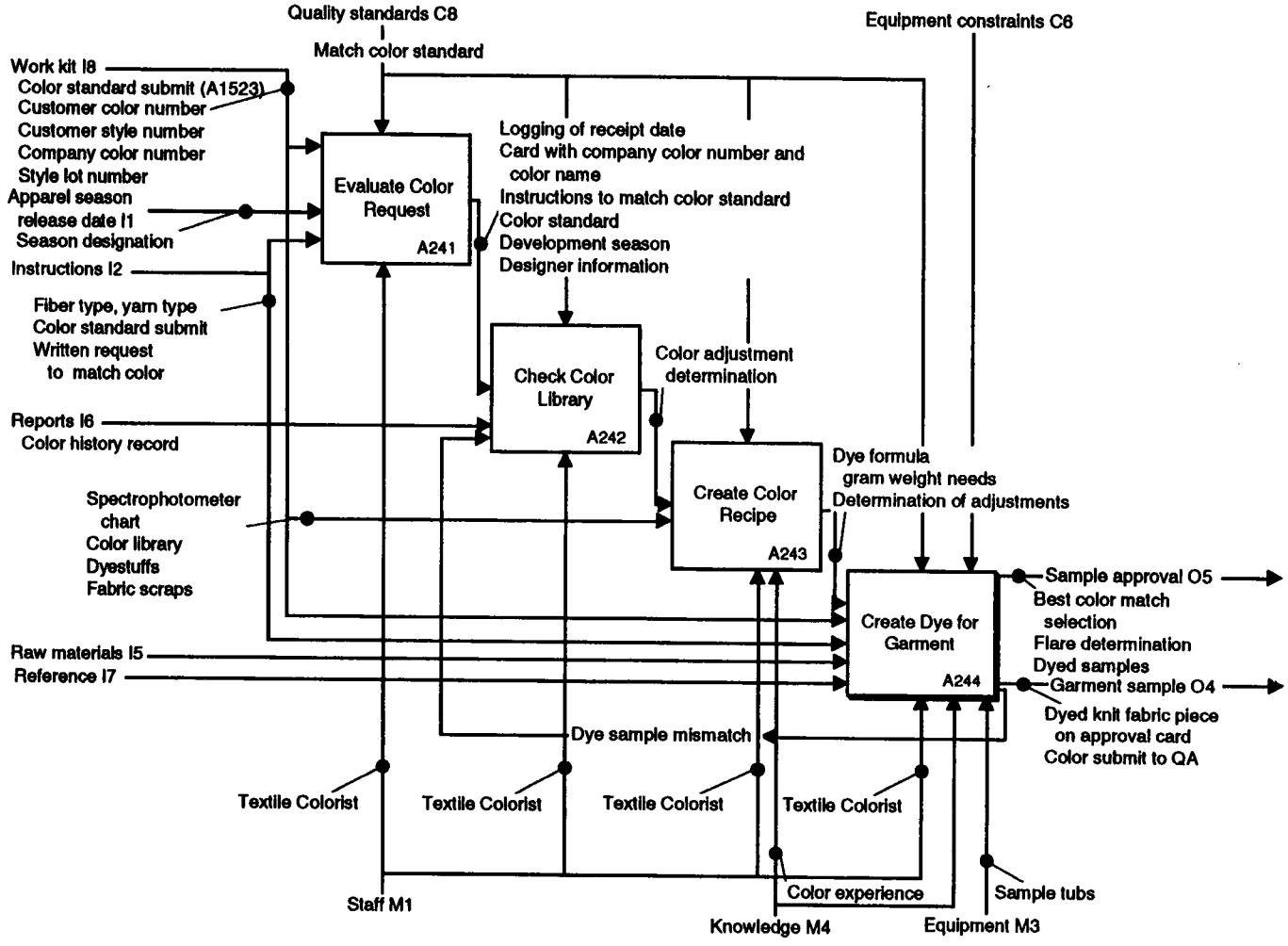
NODE: A232

Figure 50. Create technical setup (print plant).



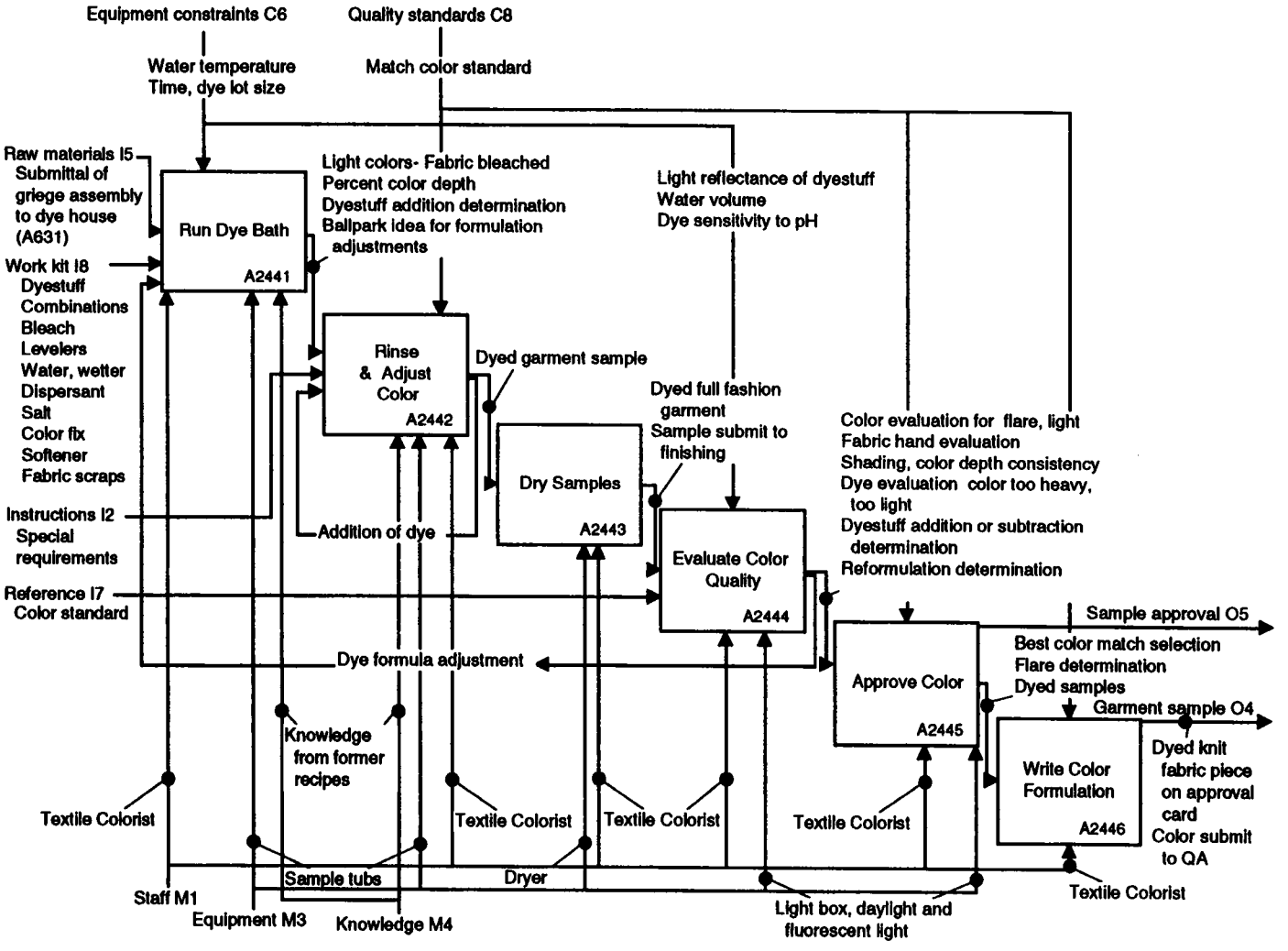
NODE: A233

Figure 51. Generate color pigment.



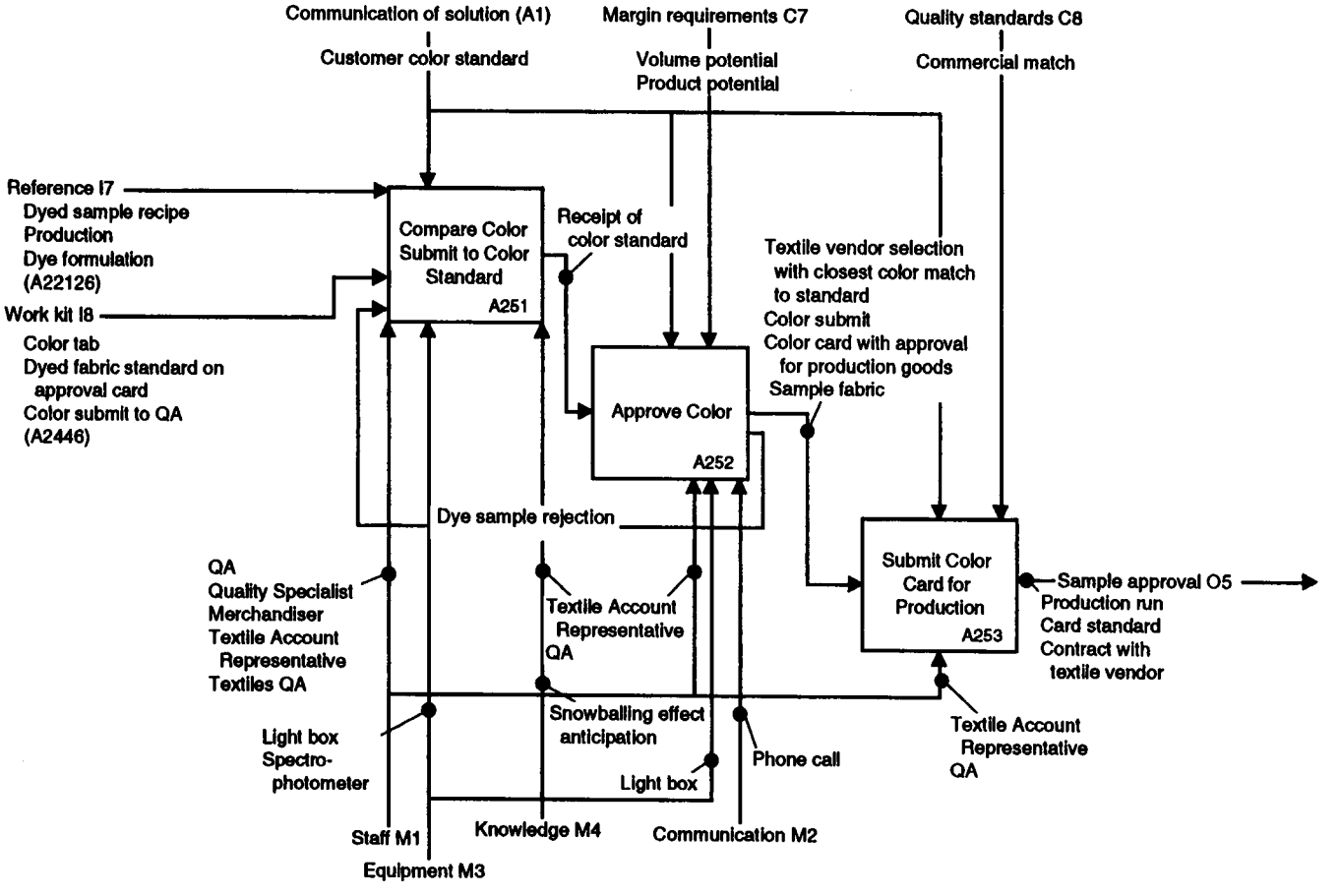
NODE: A24

Figure 52. Implement piece dye for garments.



NODE: A244

Figure 53. Create dye for garment.



NODE: A25

Figure 54. Approve dyed color samples.

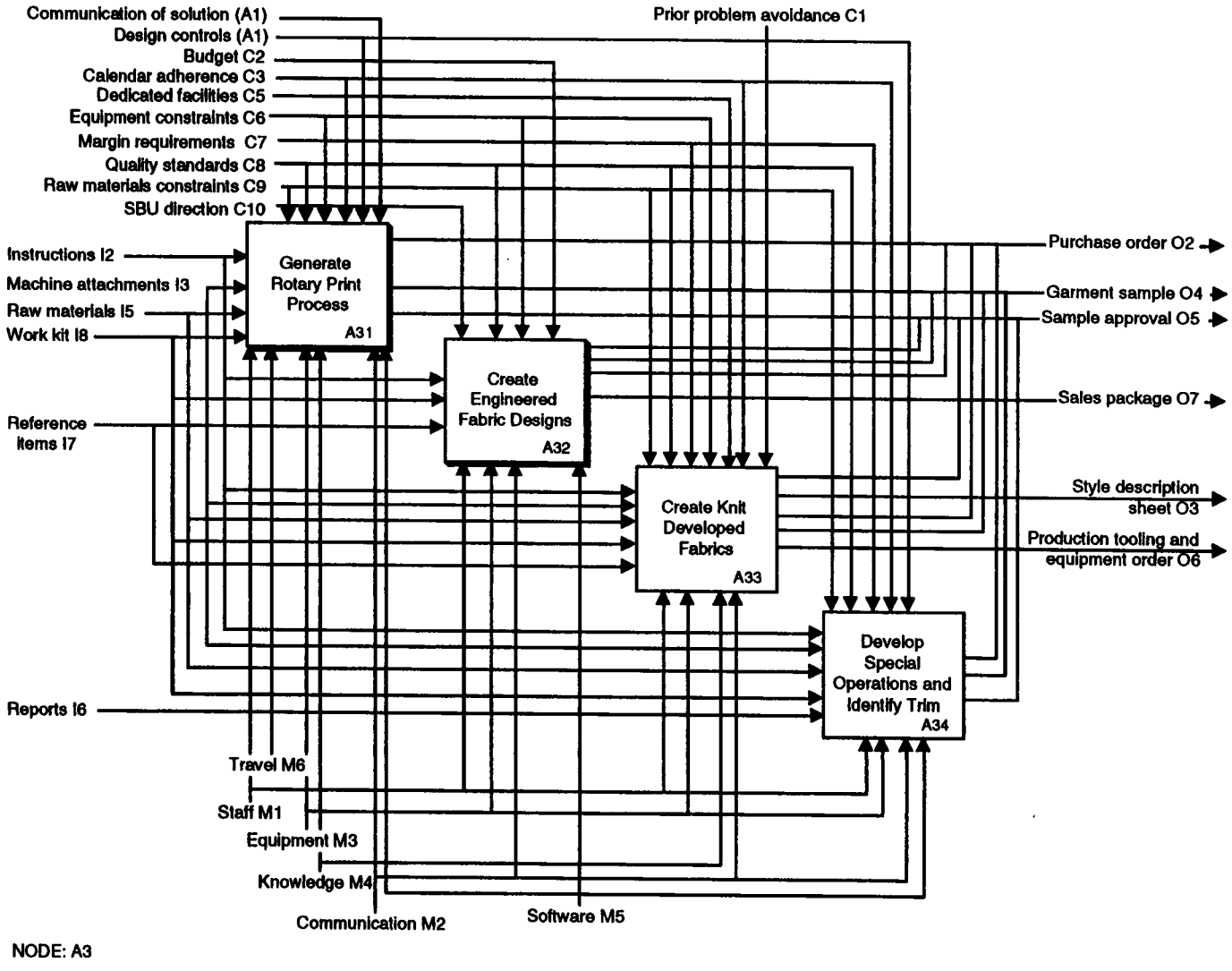


Figure 55. Implement fabric design and special operations.

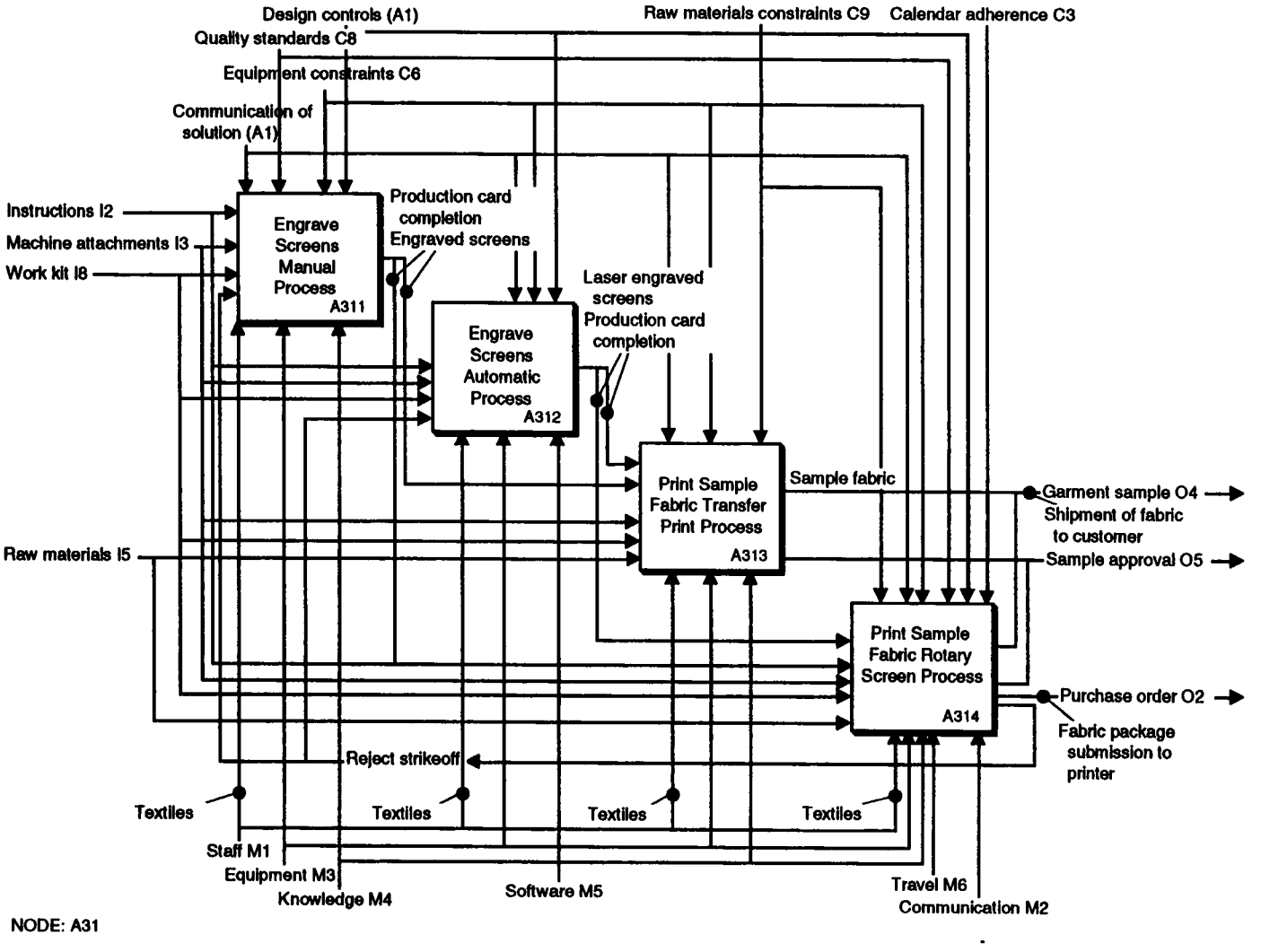


Figure 56. Generate rotary print process.

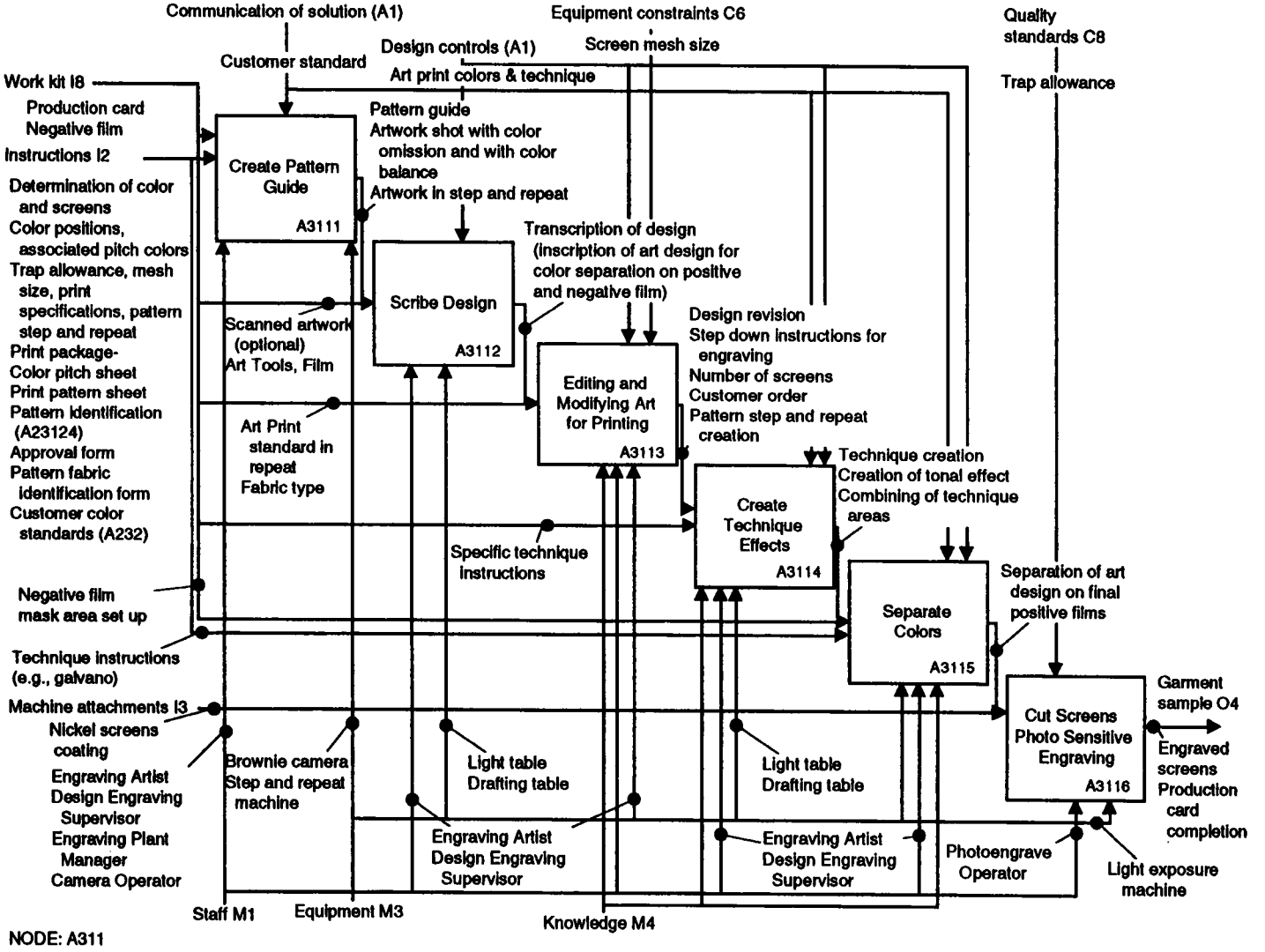


Figure 57. Engrave screens manual process.

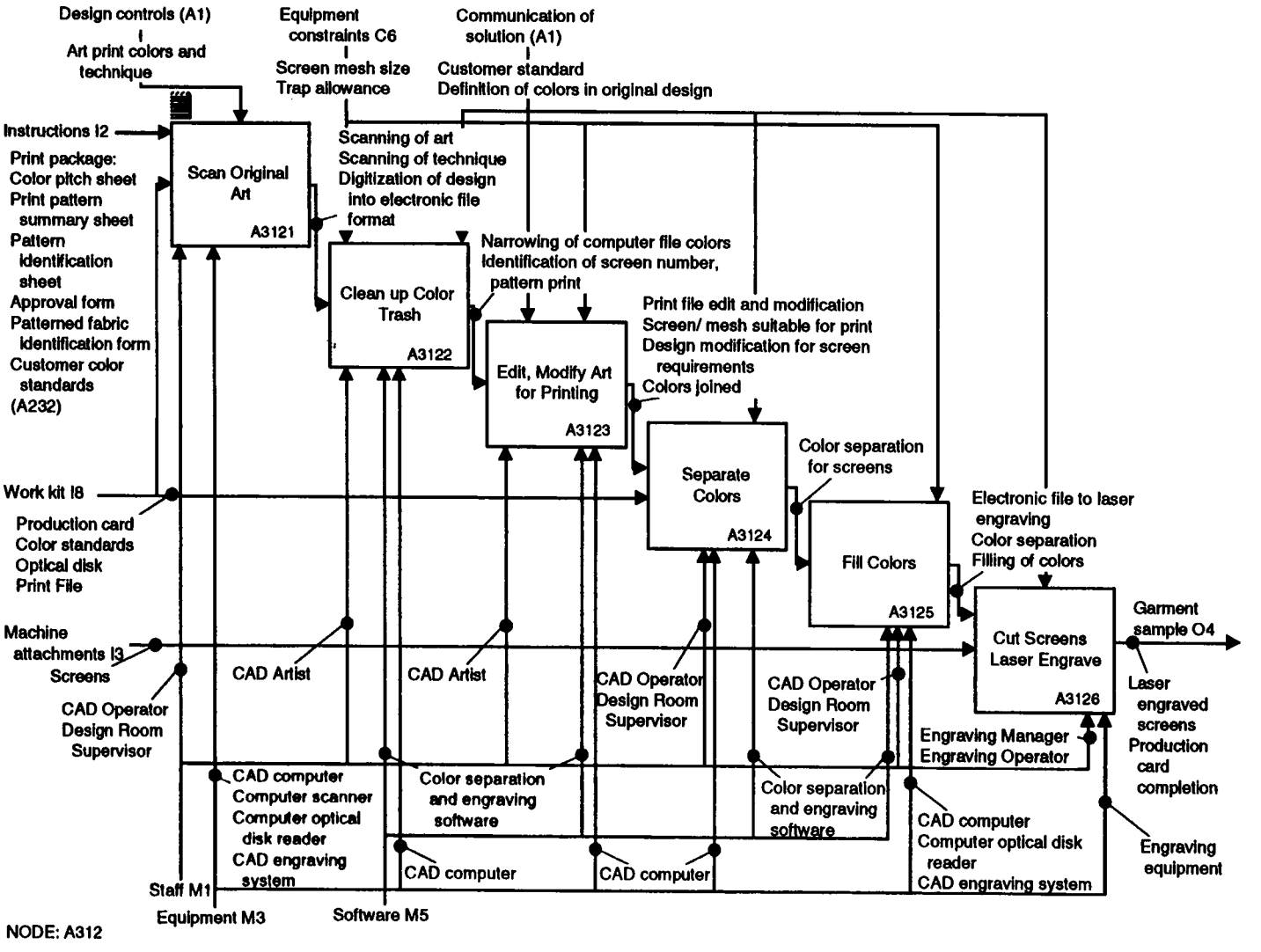
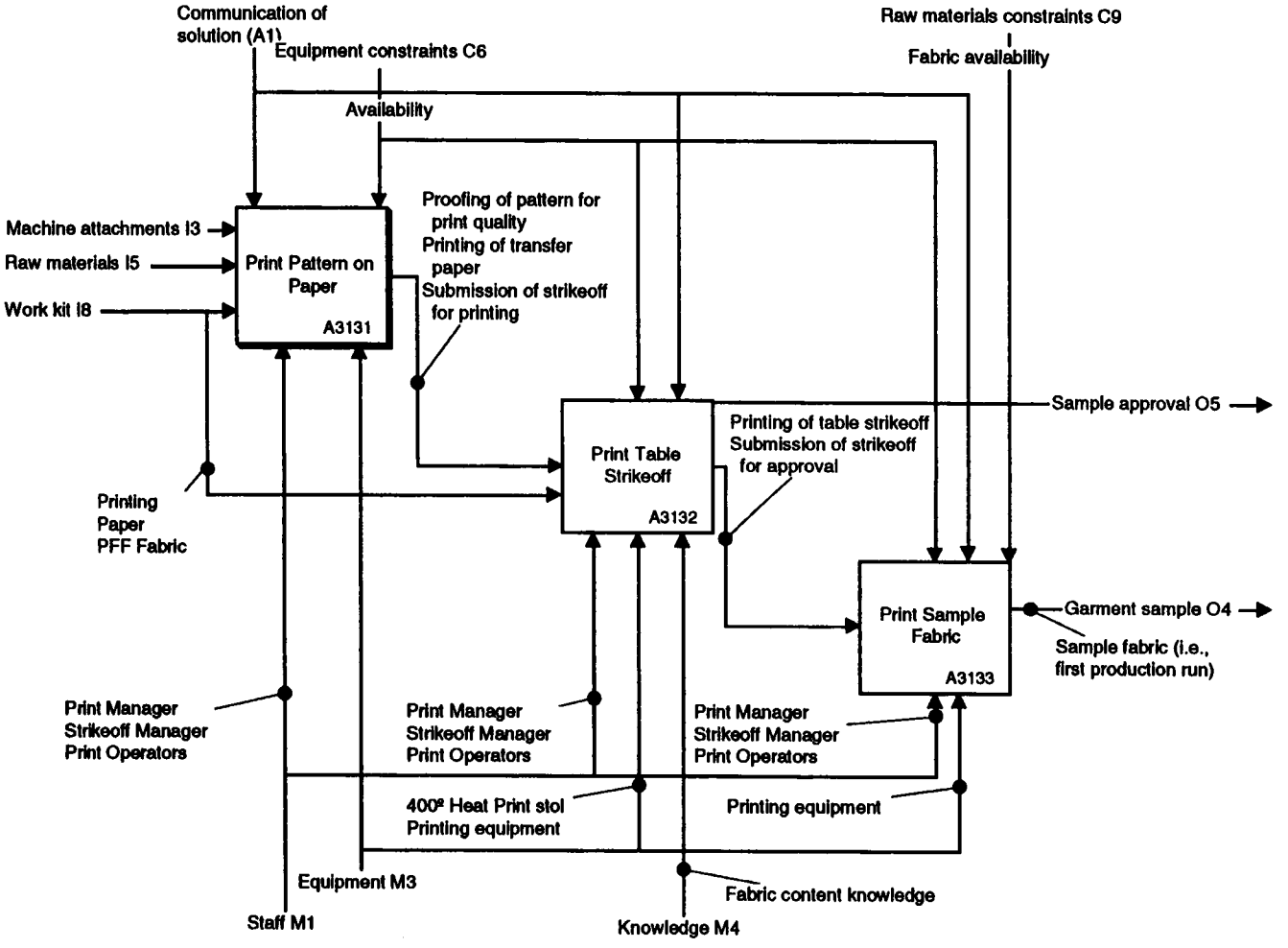
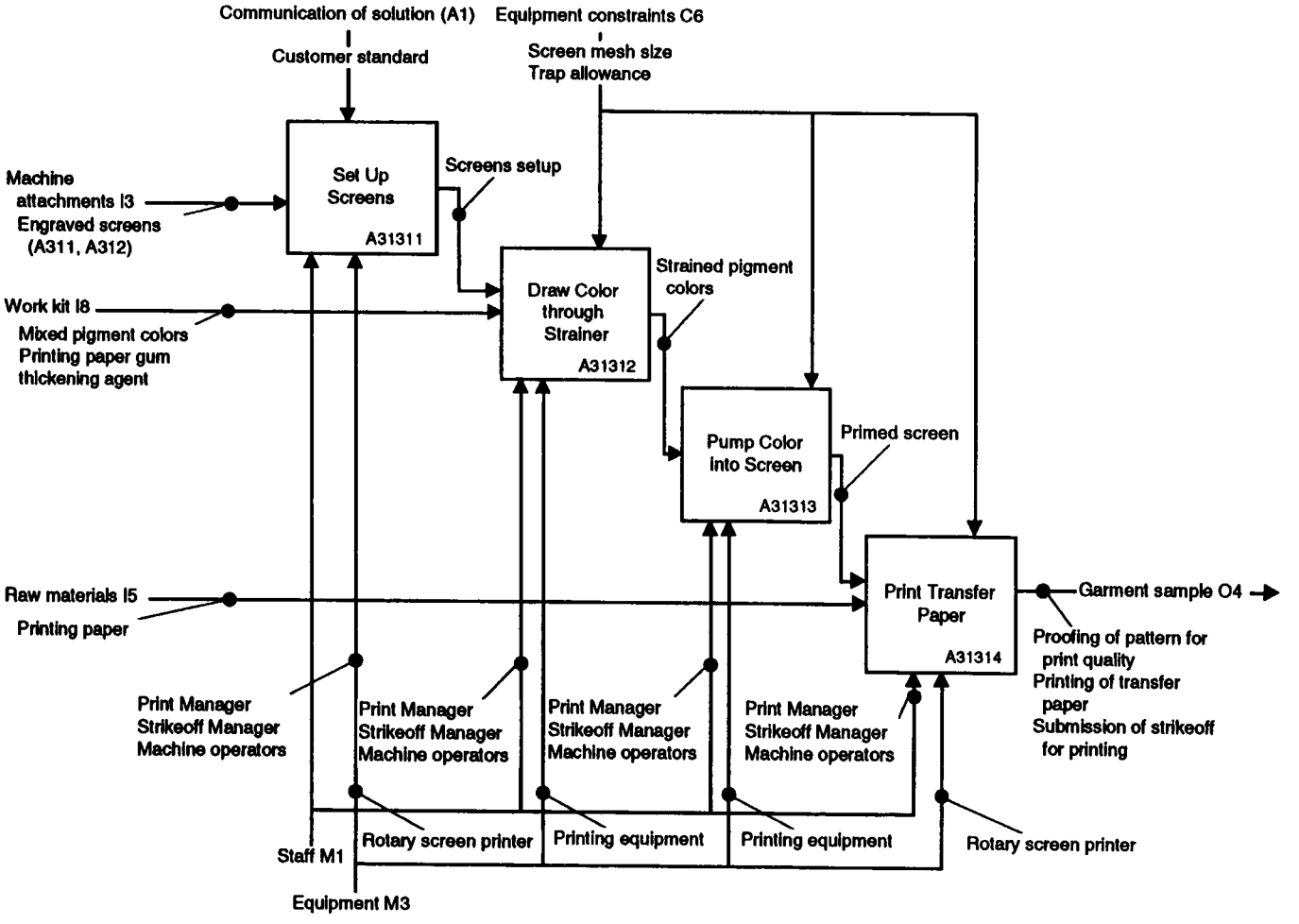


Figure 58. Engrave screens automatic process.



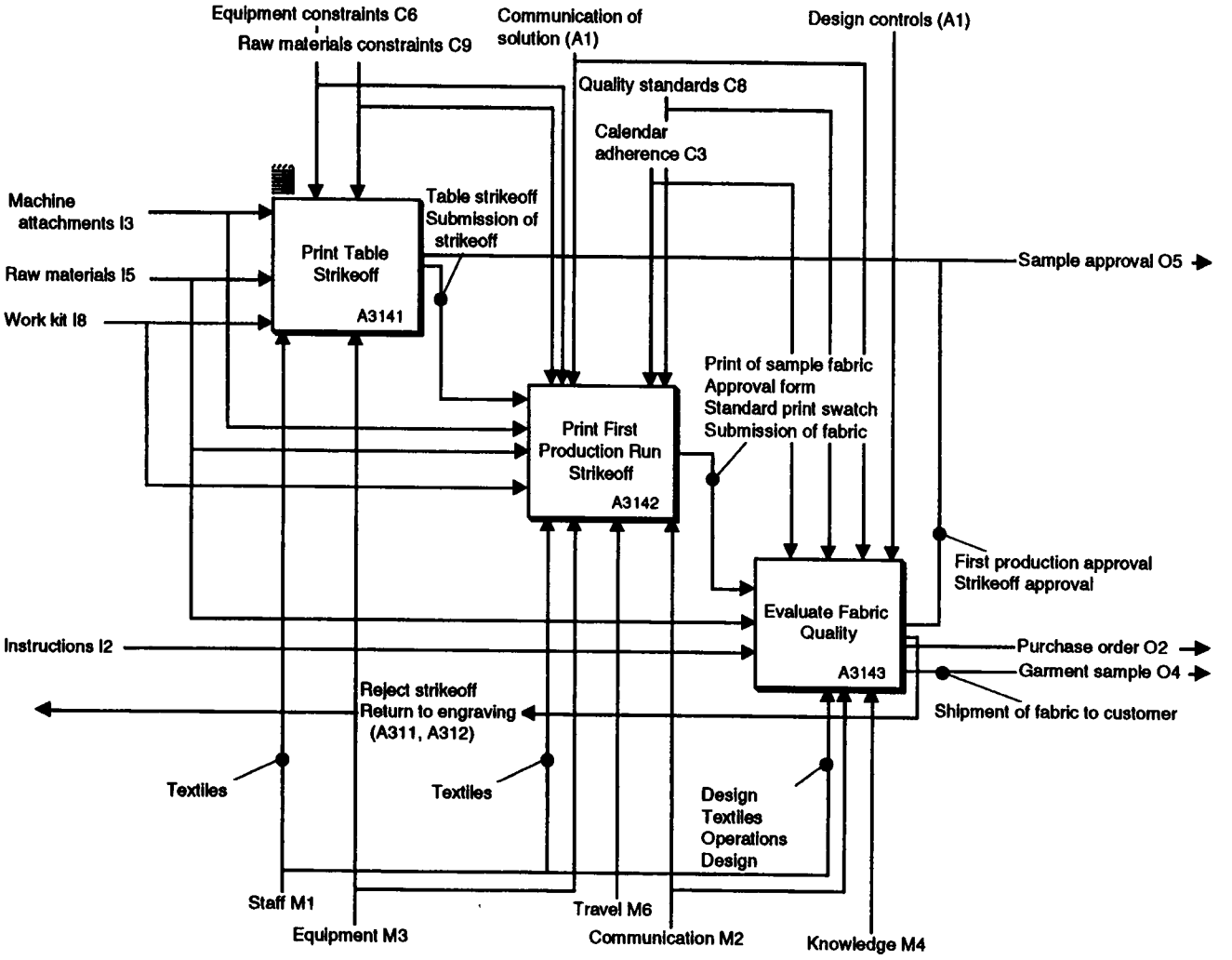
NODE: A313

Figure 59. Print sample fabric transfer print process.



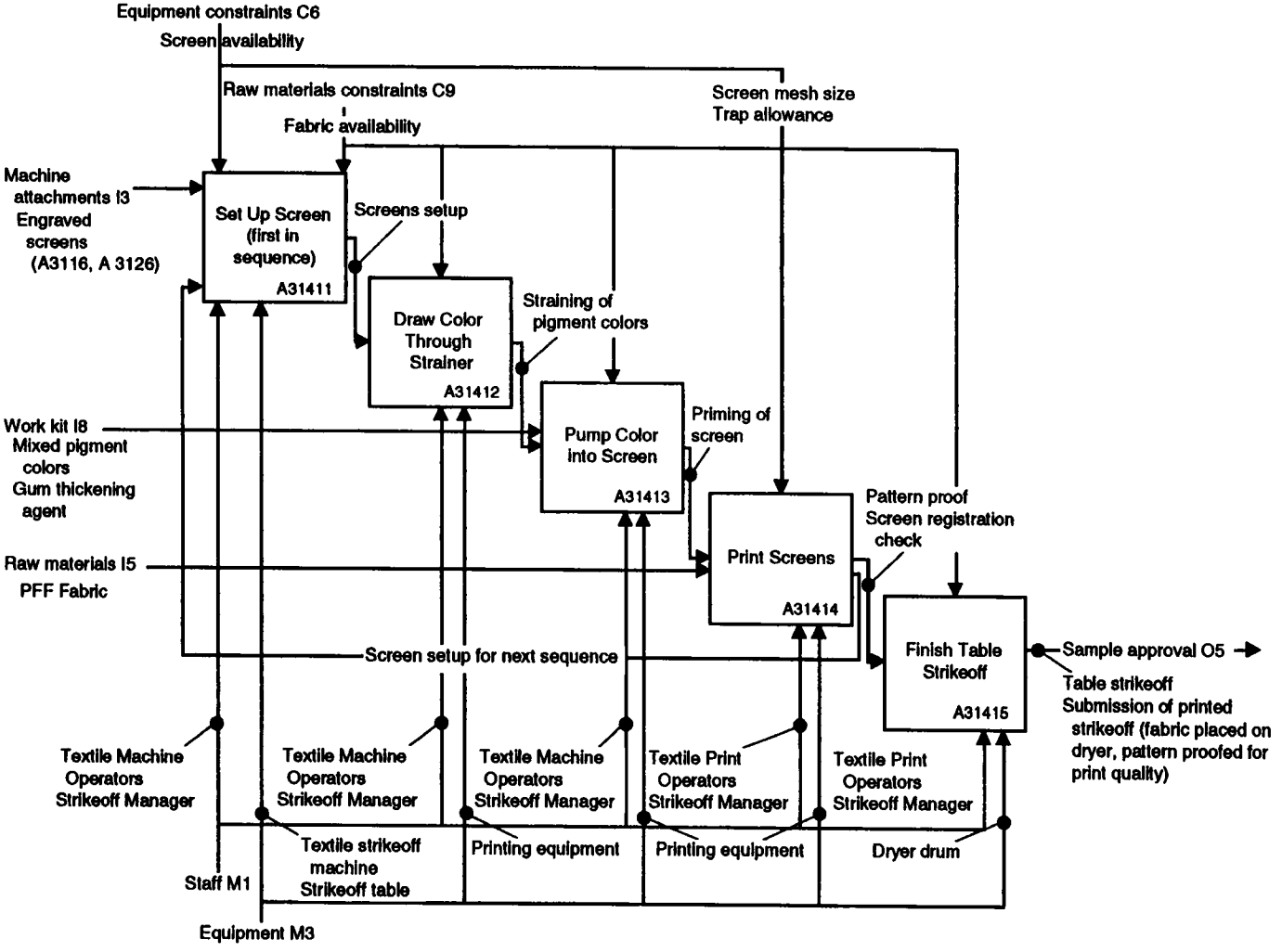
NODE: A3131

Figure 60. Print pattern on paper.



NODE: A314

Figure 61. Print sample fabric rotary screen process.



NODE: A3141

Figure 62. Print table strikeoff.

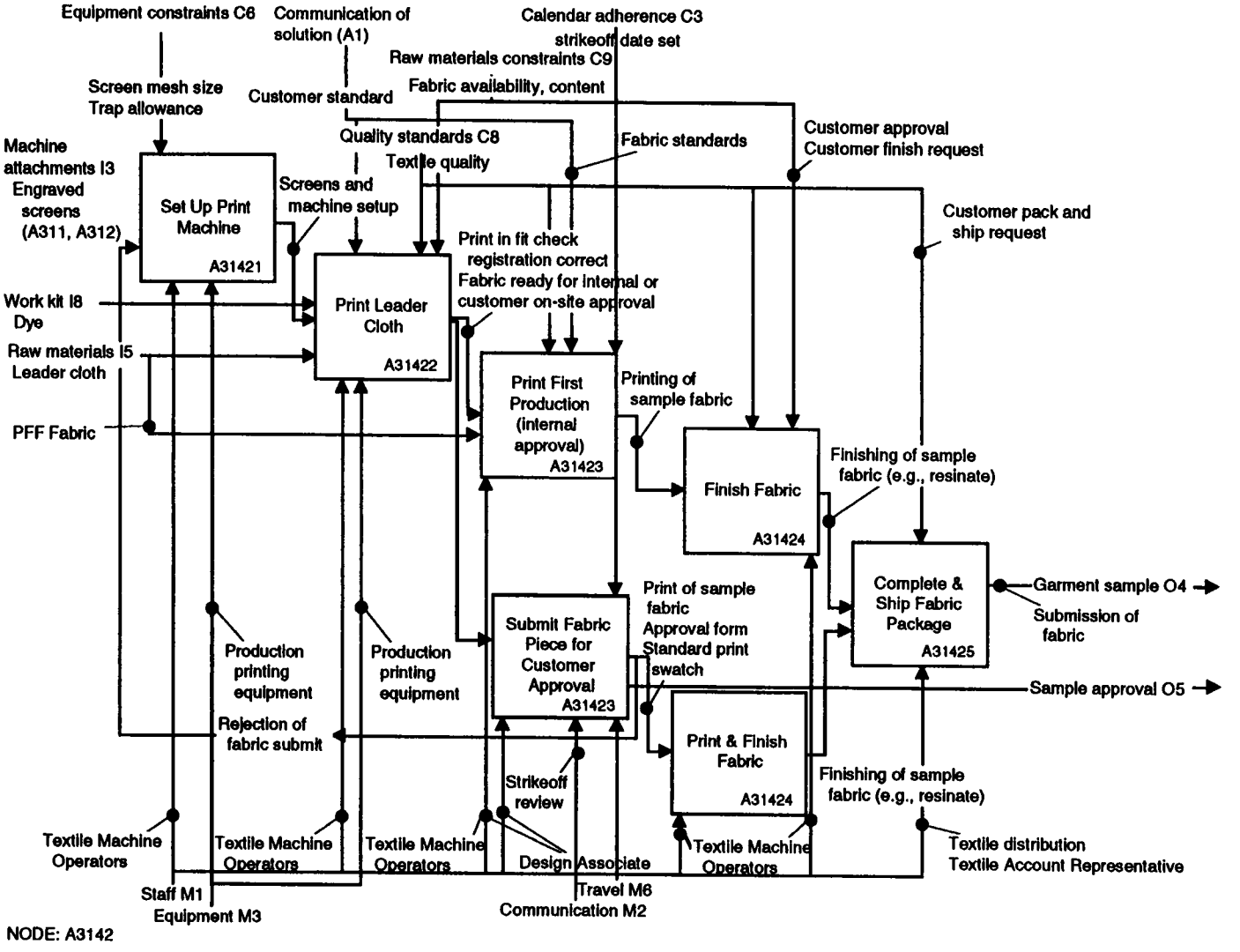
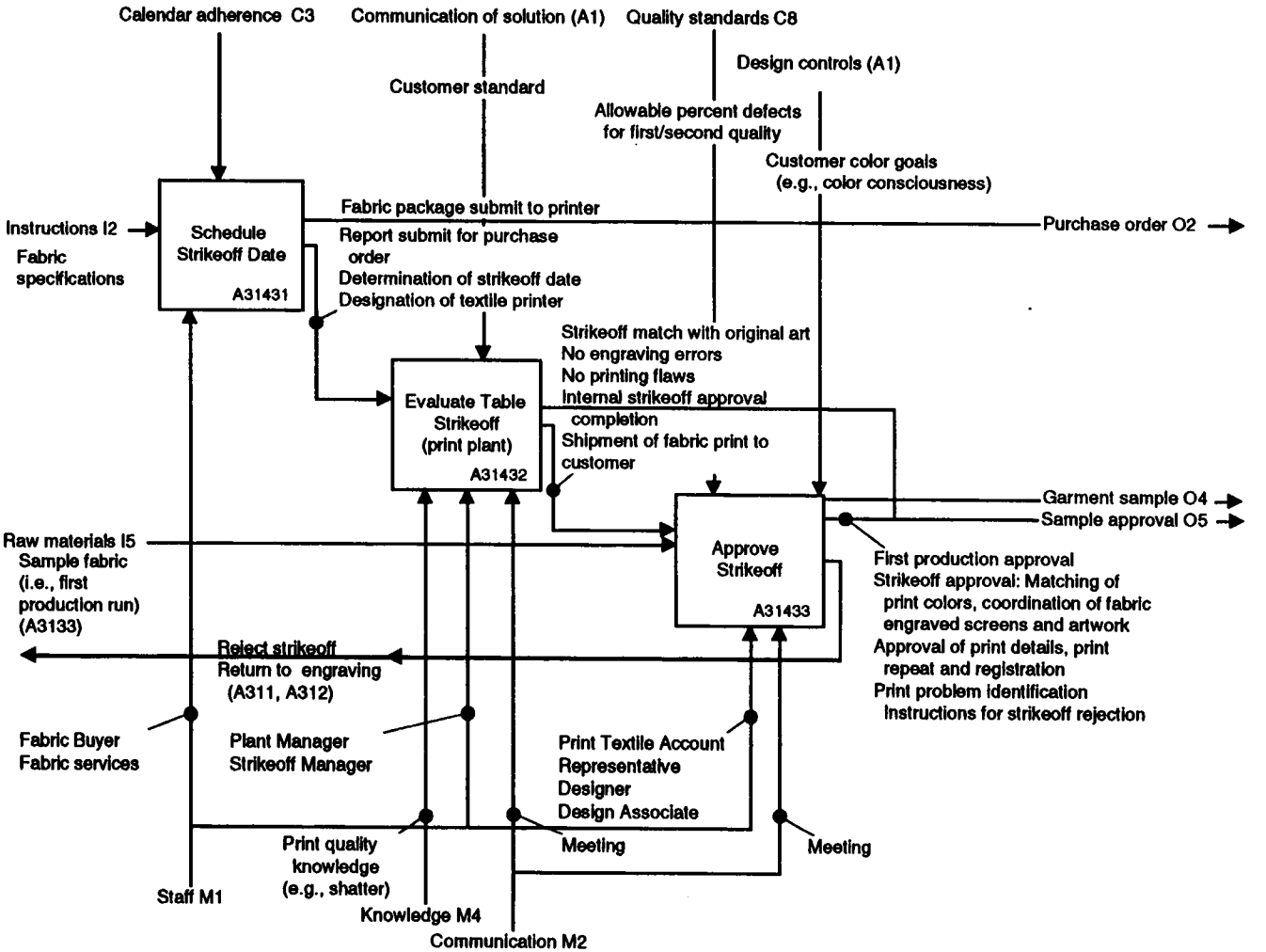
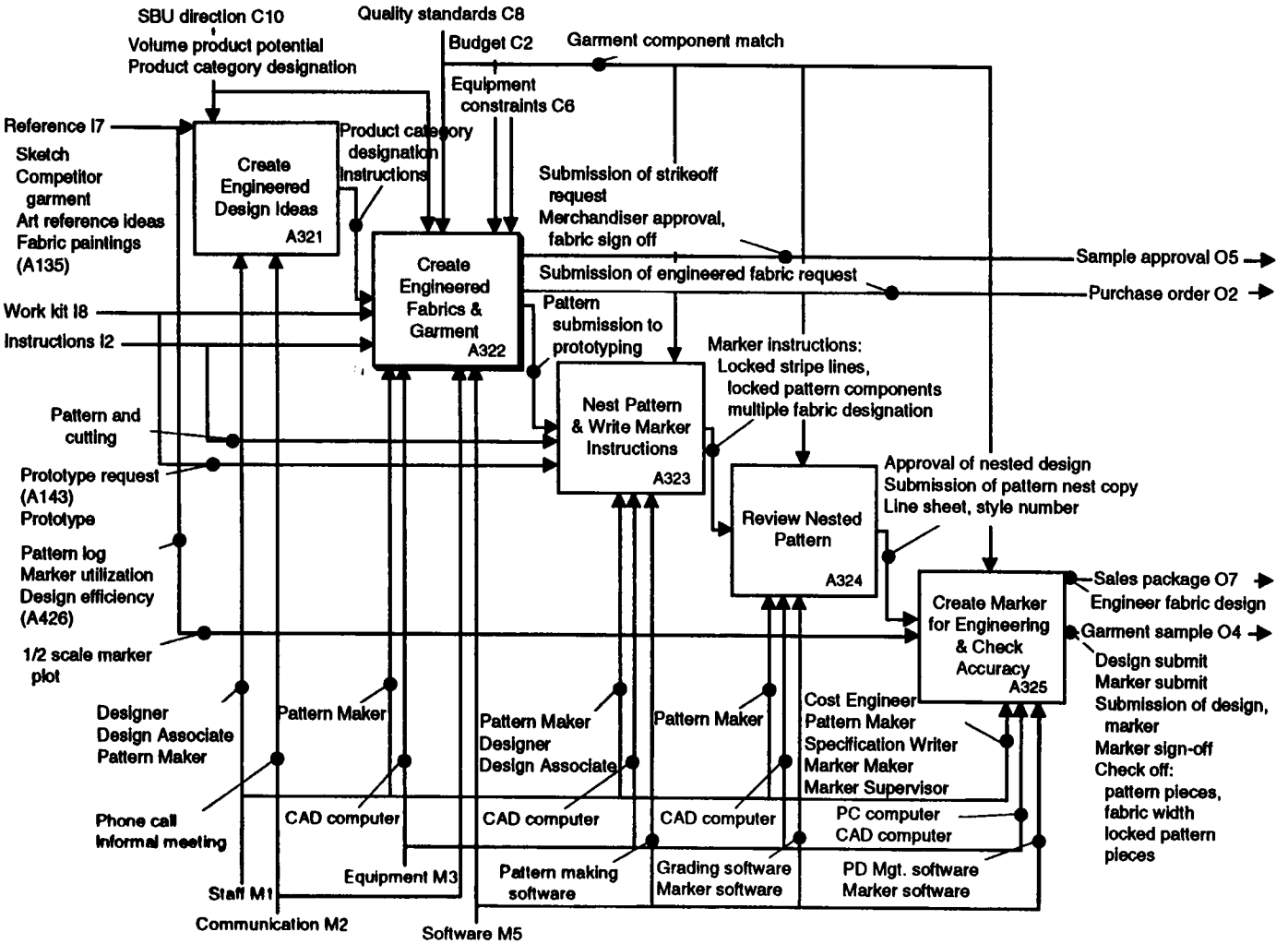


Figure 63. Print first production run strikeoff.



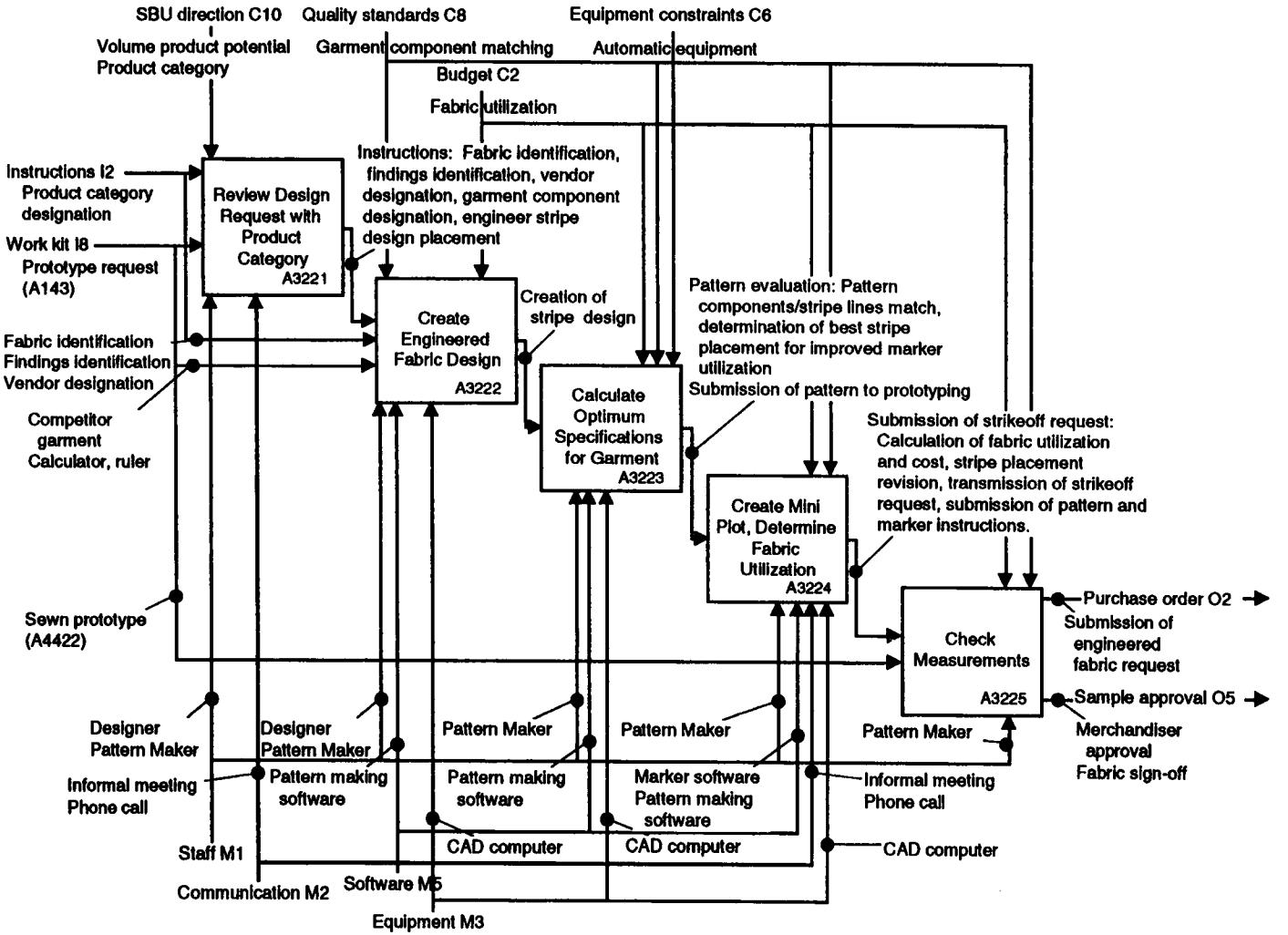
NODE: A3143

Figure 64. Evaluate fabric quality.



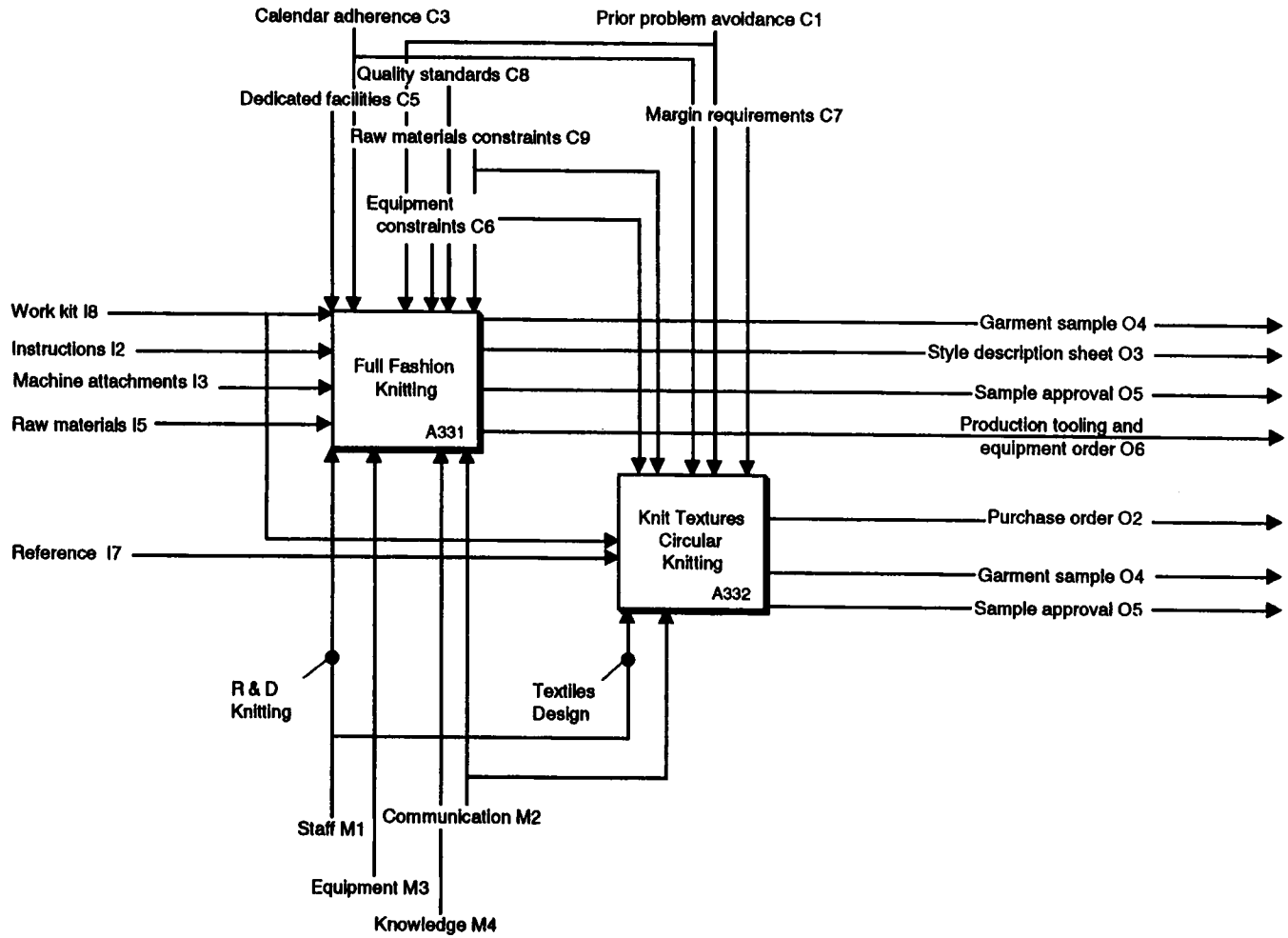
NODE: A32

Figure 65. Create engineered fabric designs.



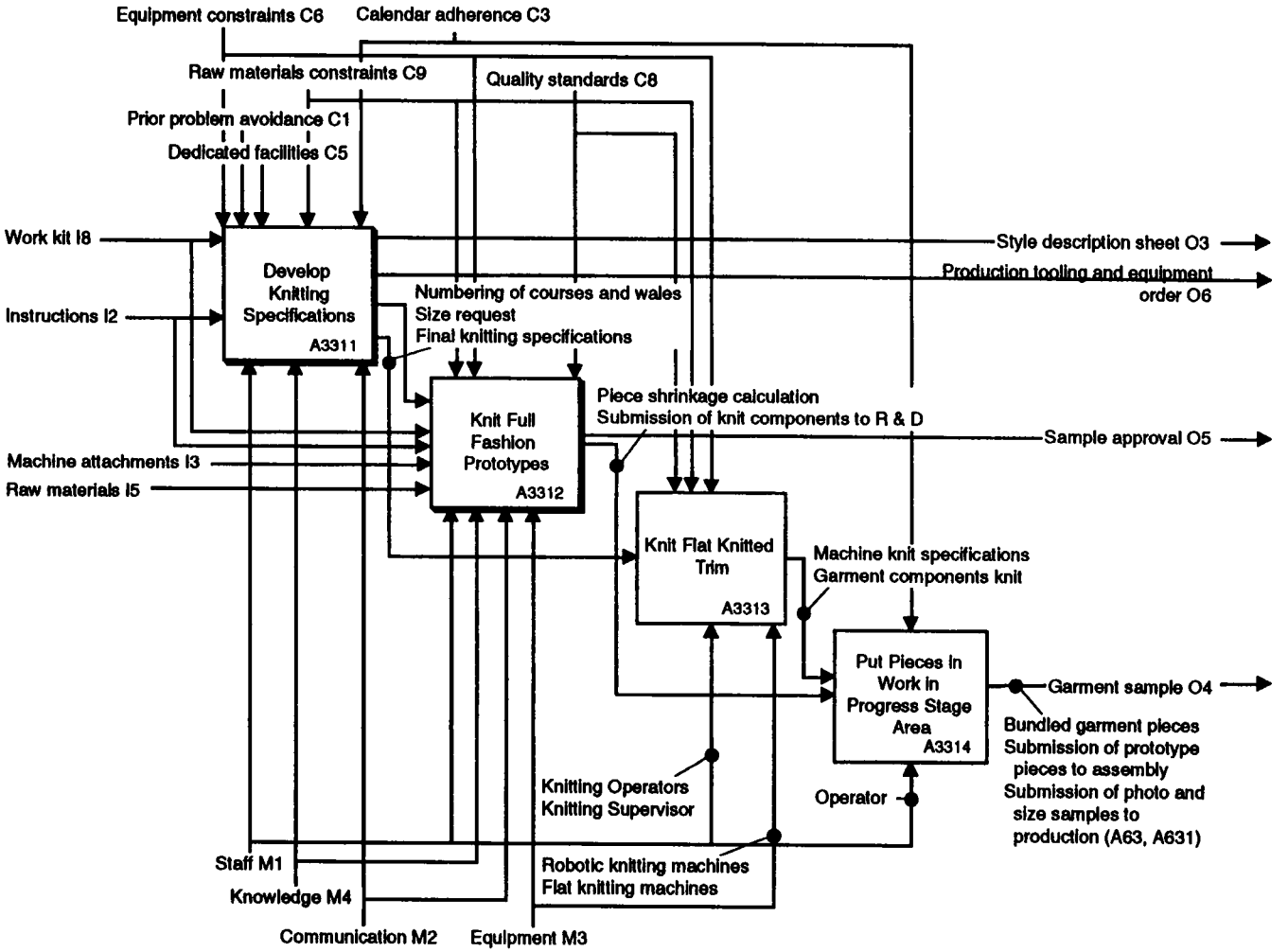
NODE: A322

Figure 66. Create engineer fabrics and garment design.



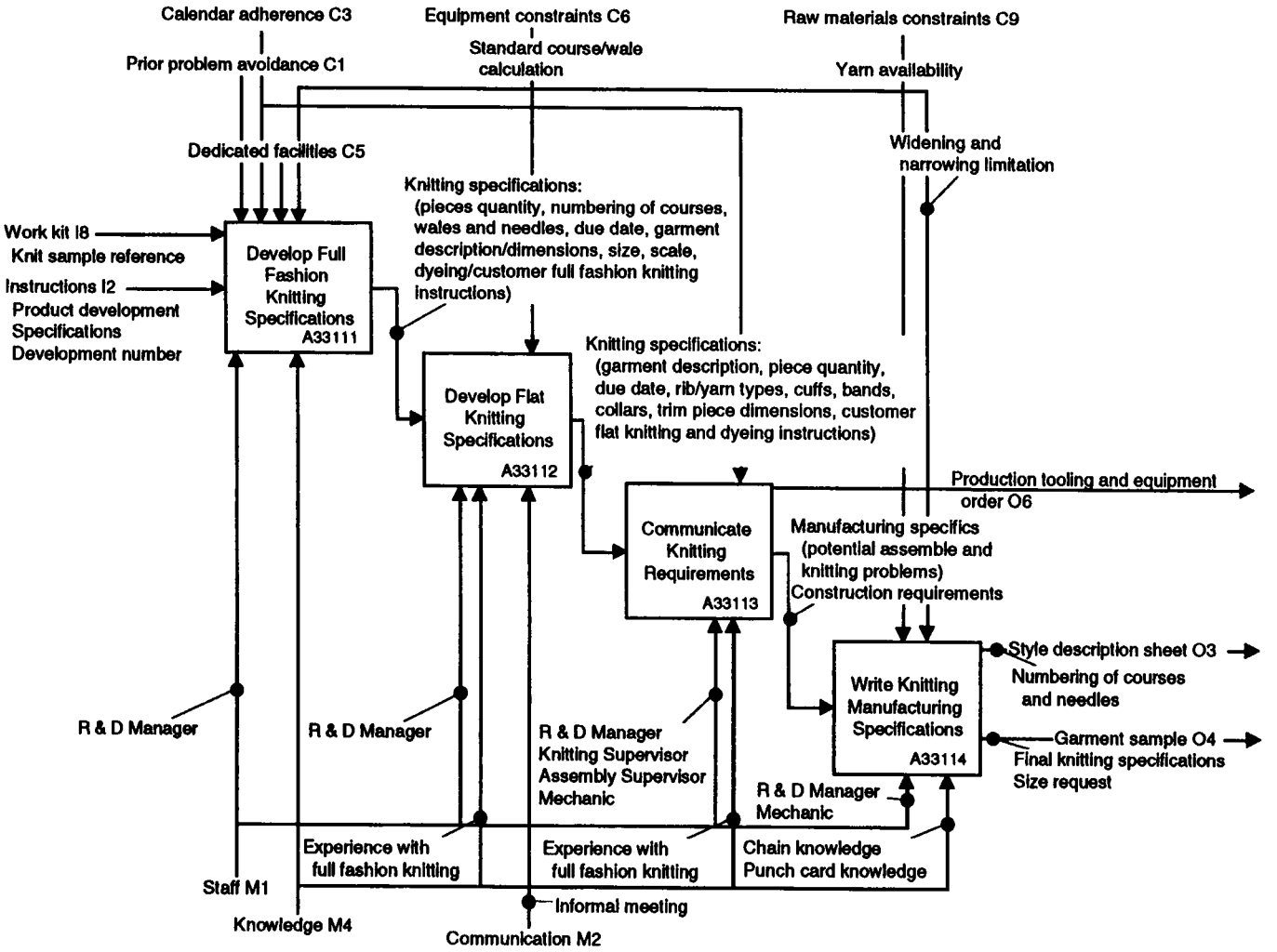
NODE: 33

Figure 67. Create knit developed fabrics.



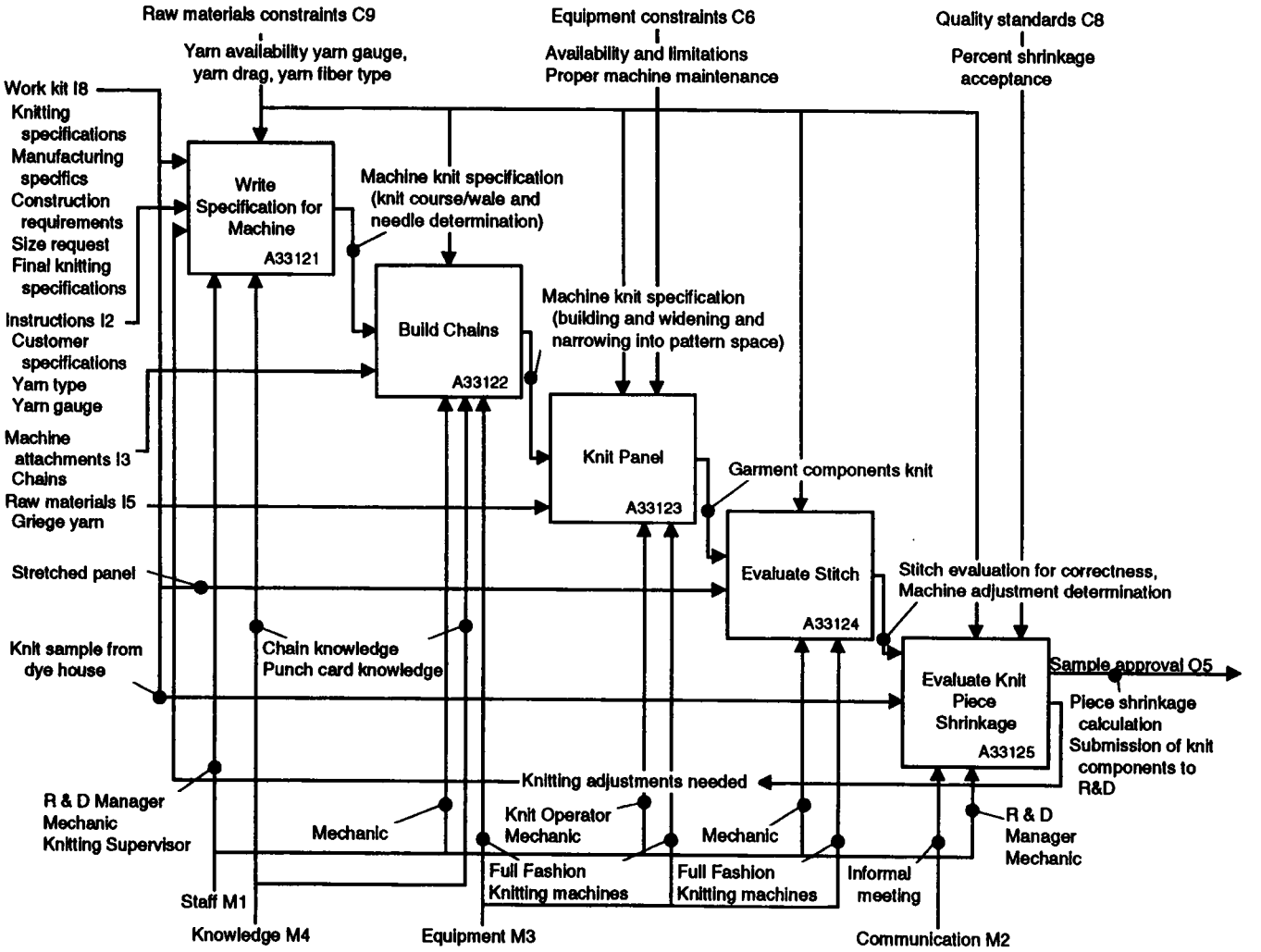
NODE: A331

Figure 68. Full fashion knitting.



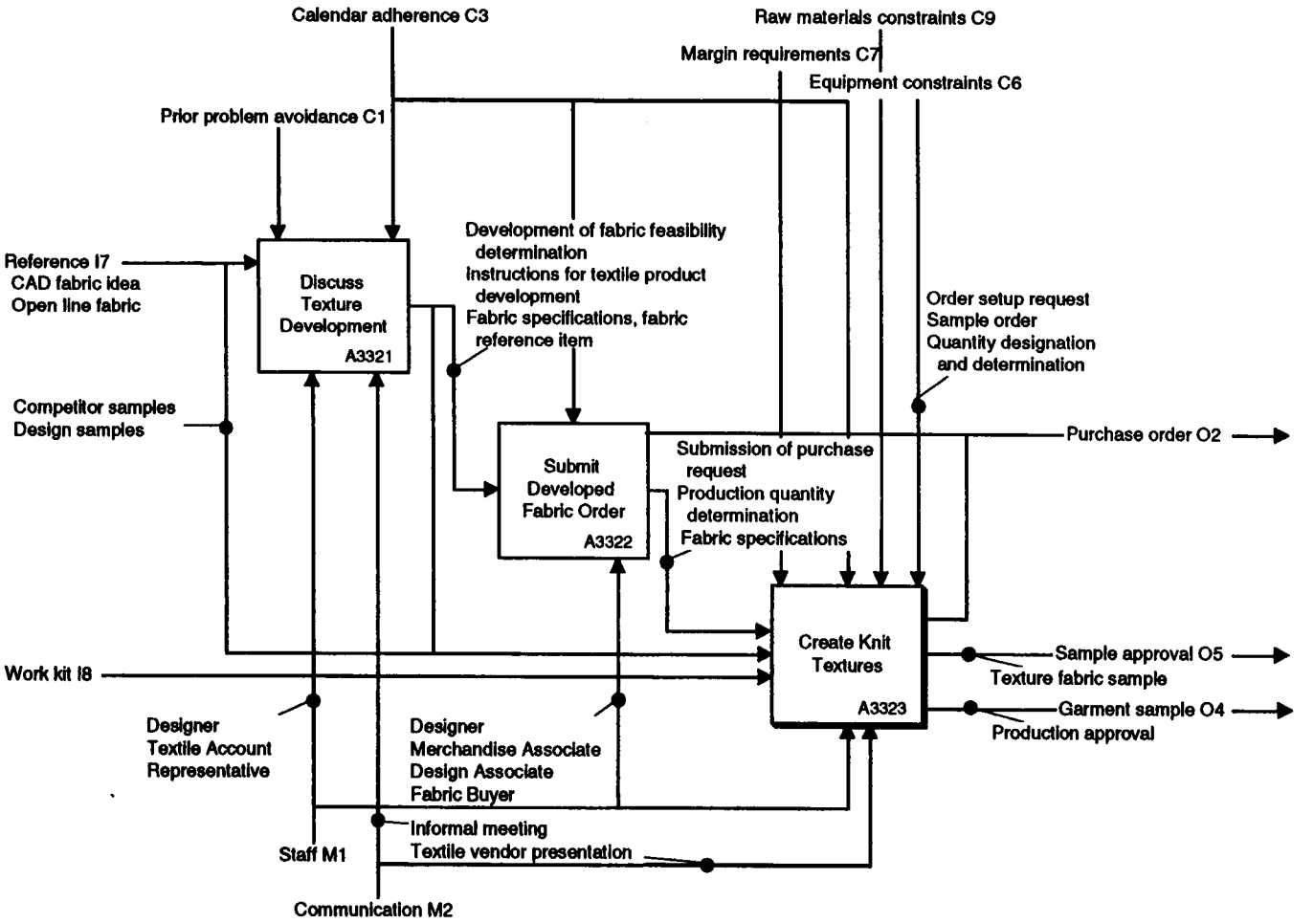
NODE: A3311

Figure 69. Develop knitting specifications.



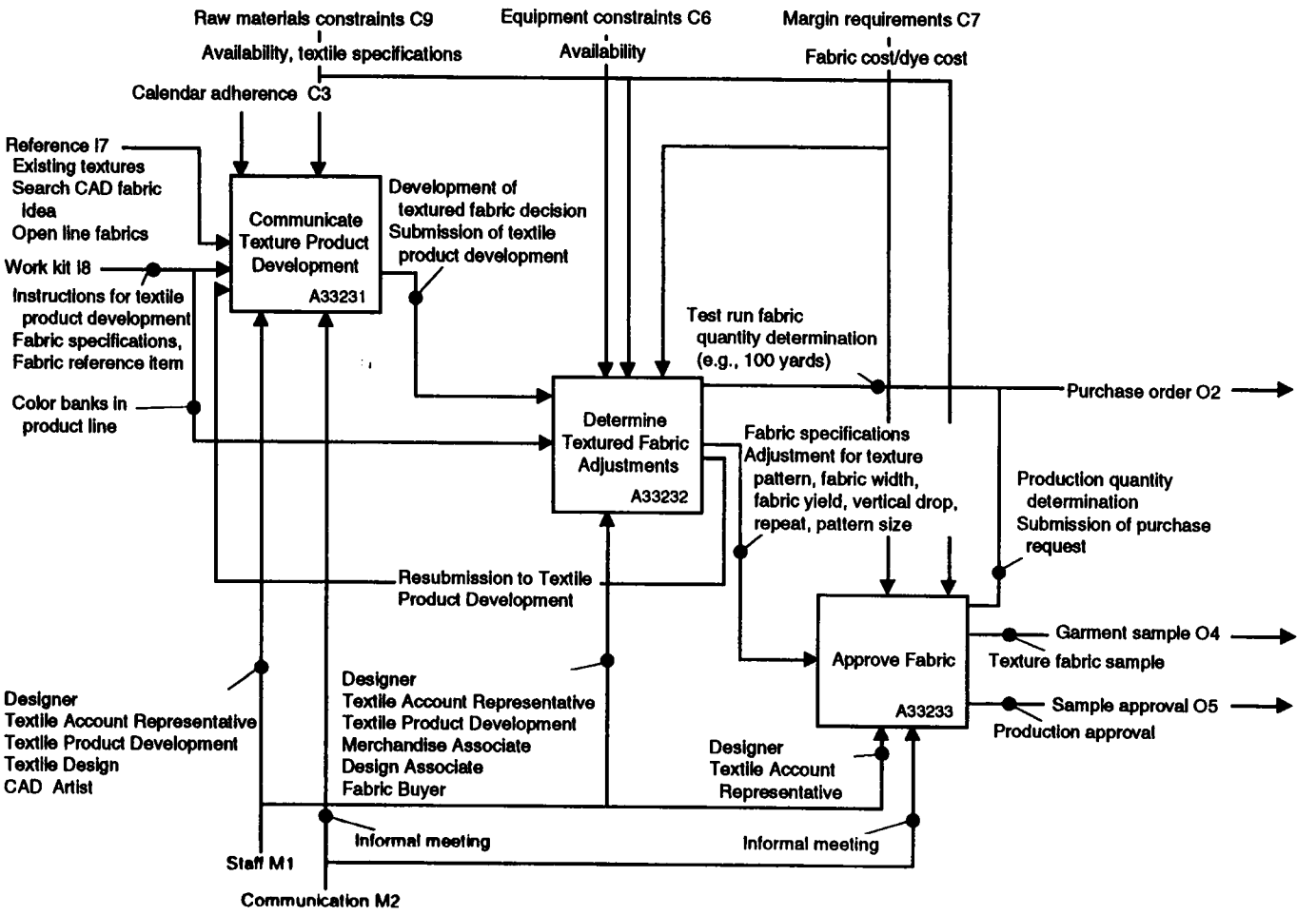
NODE: A3312

Figure 70. Knit full fashion prototypes.



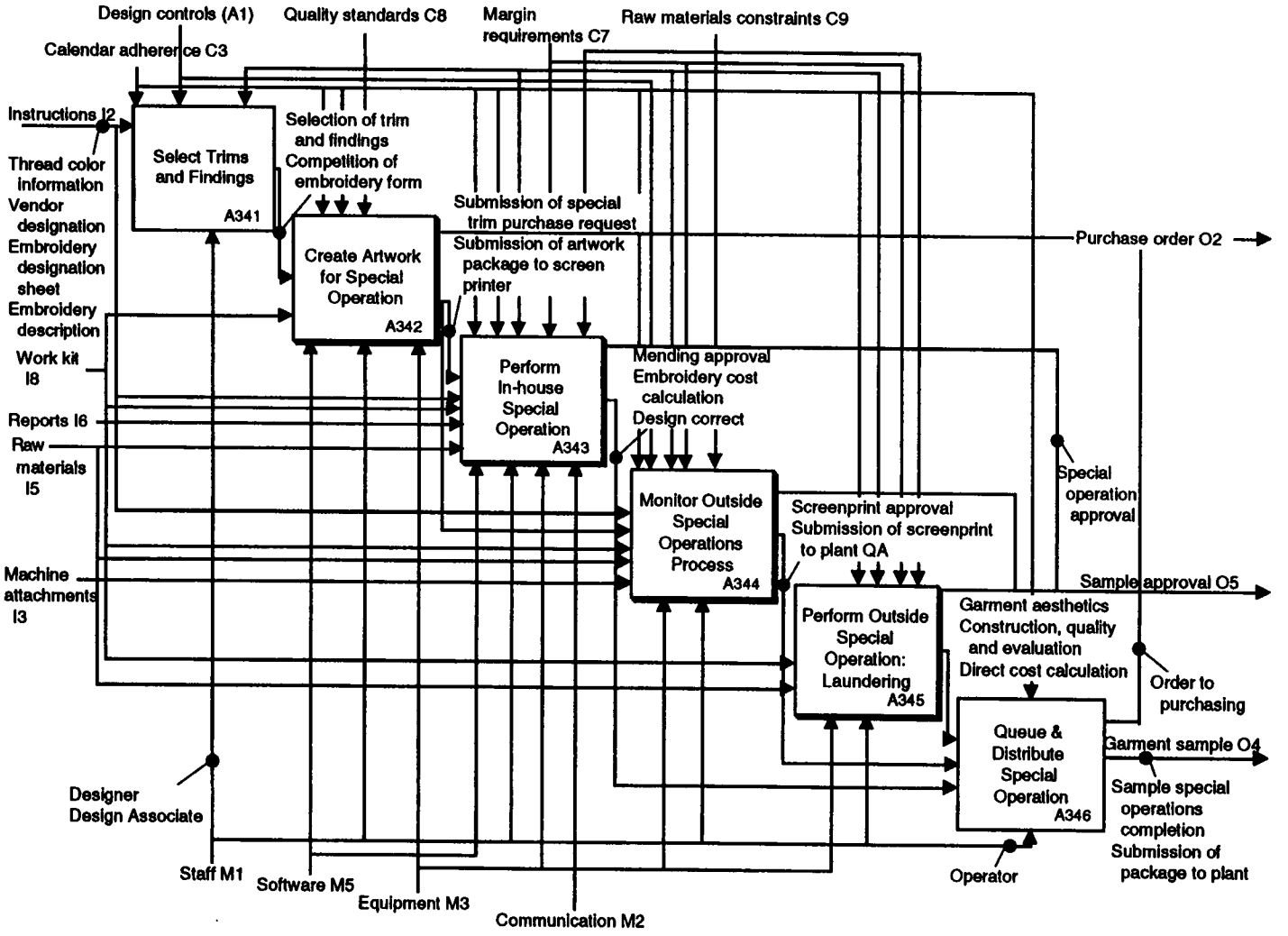
NODE: A332

Figure 71. Knit textures circular knitting.



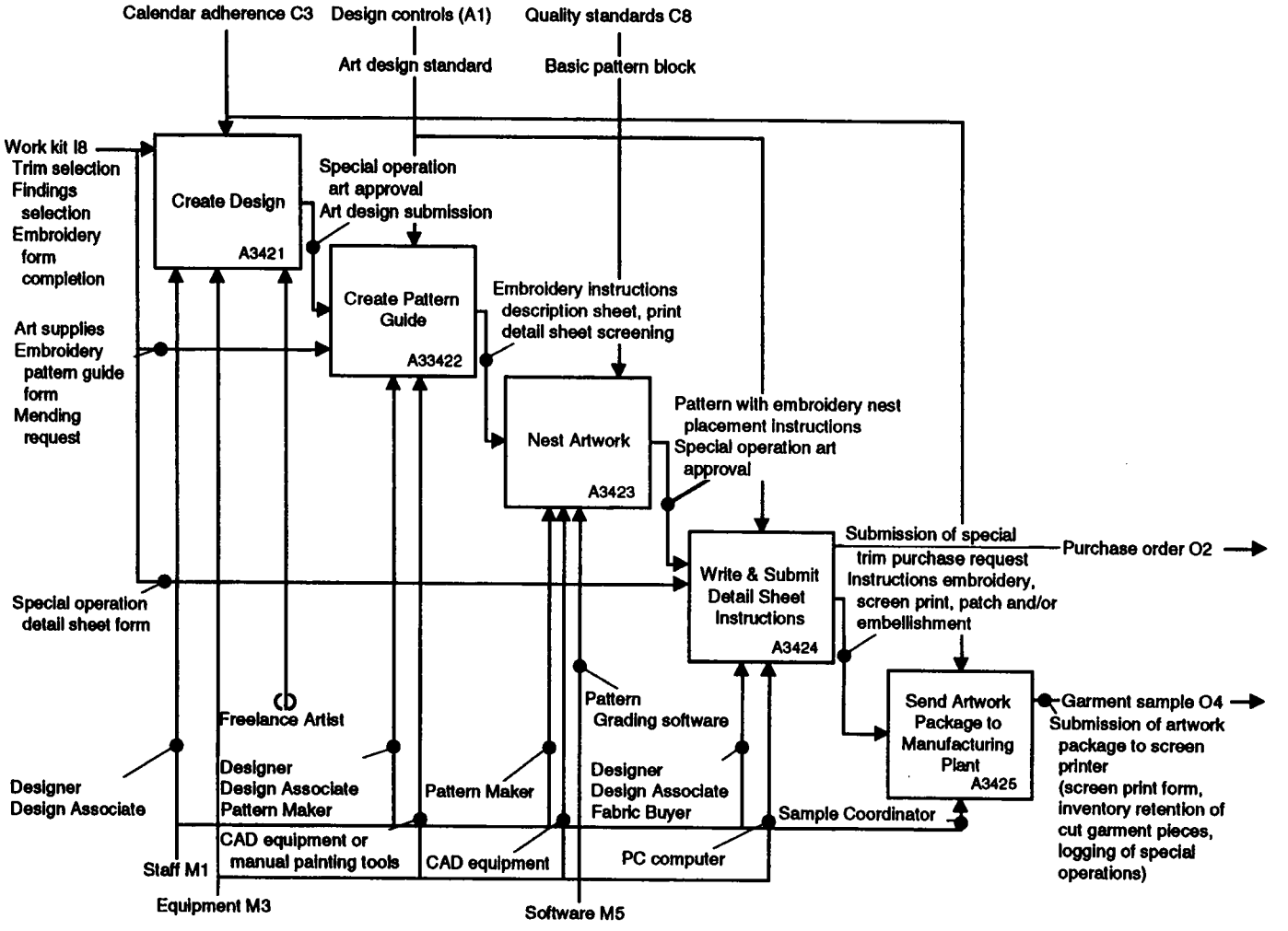
NODE A3323

Figure 72. Create knit textures.



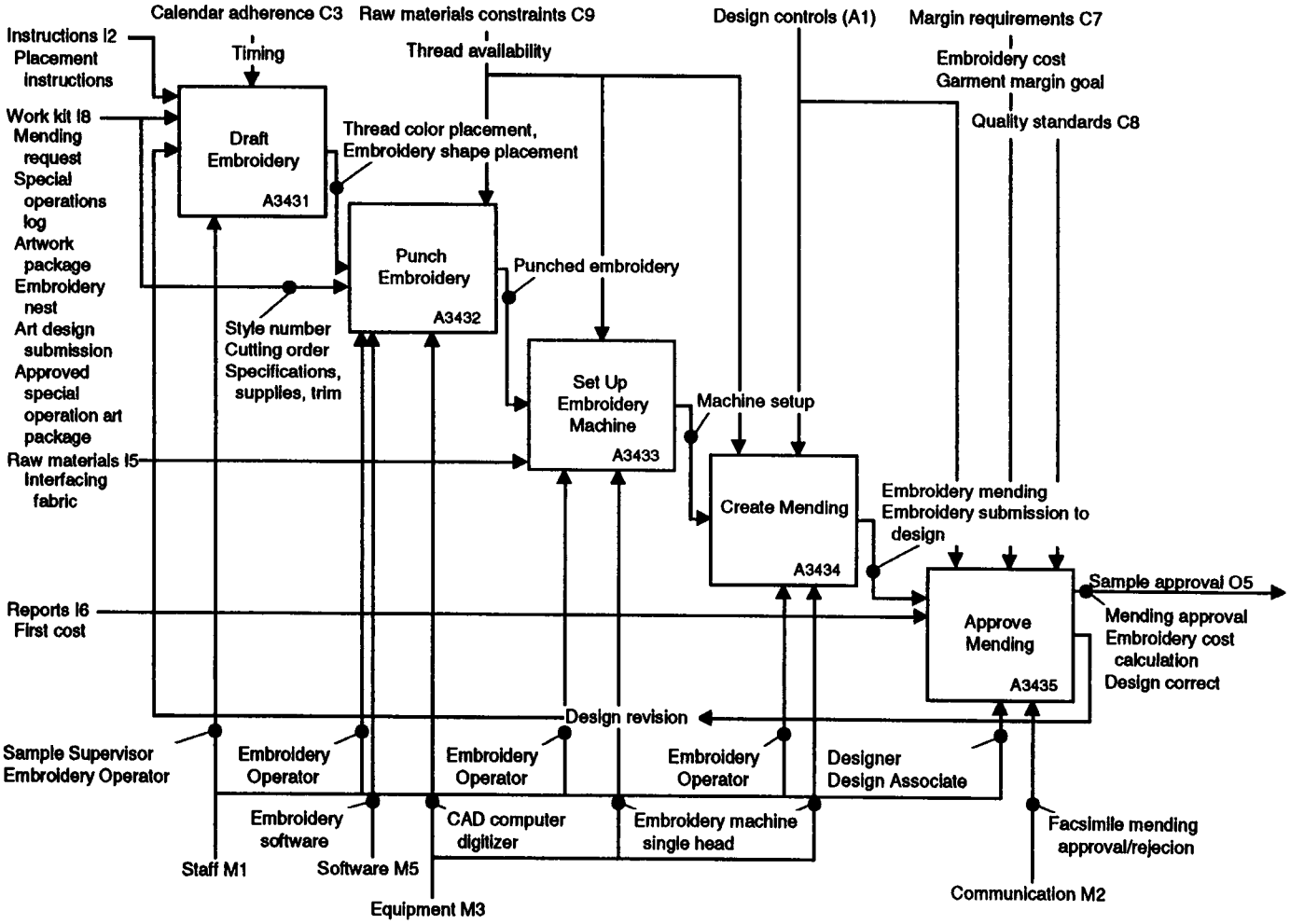
NODE: A34

Figure 73. Develop special operations and identify trim.



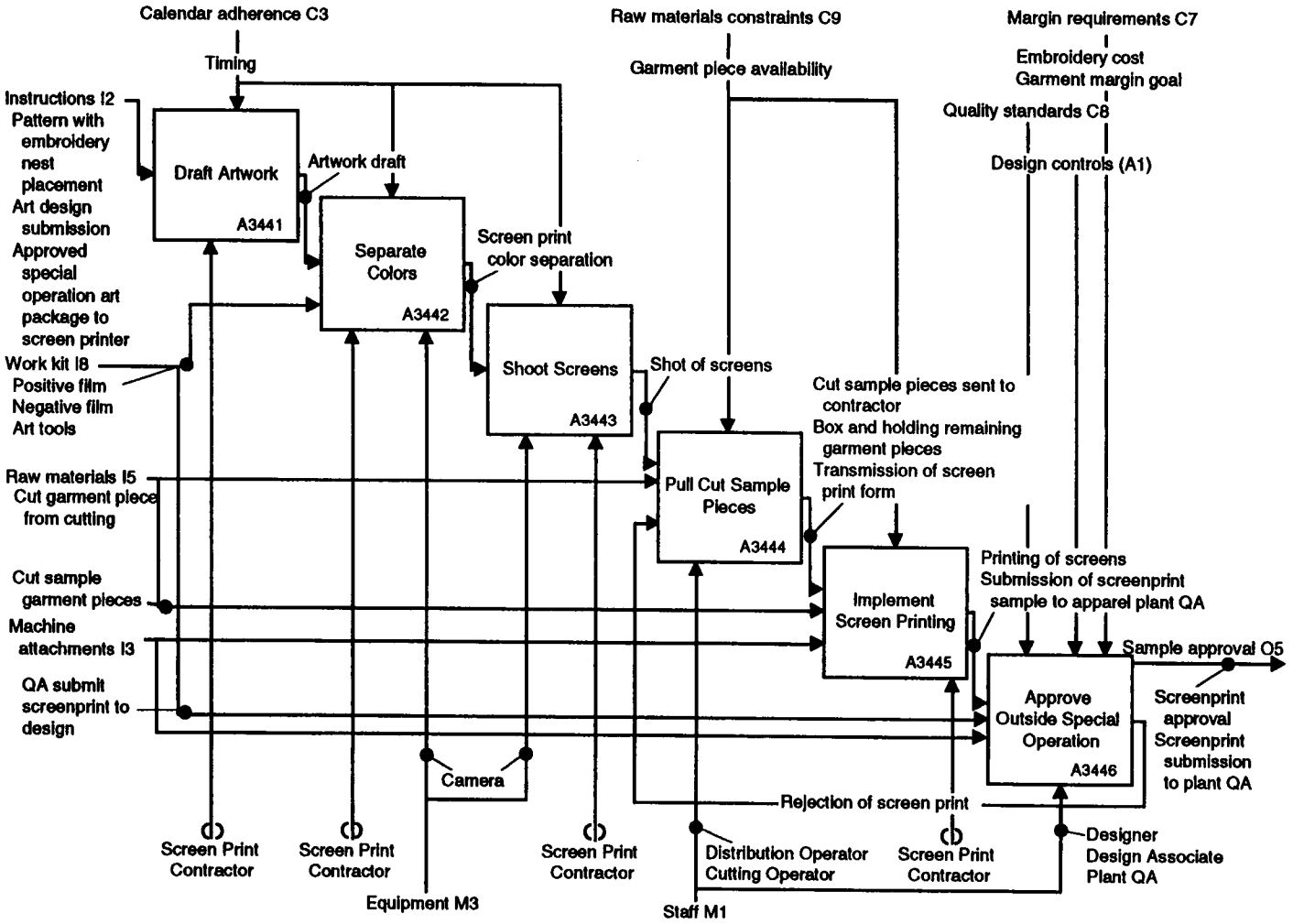
NODE: A342

Figure 74. Create artwork for special operation.



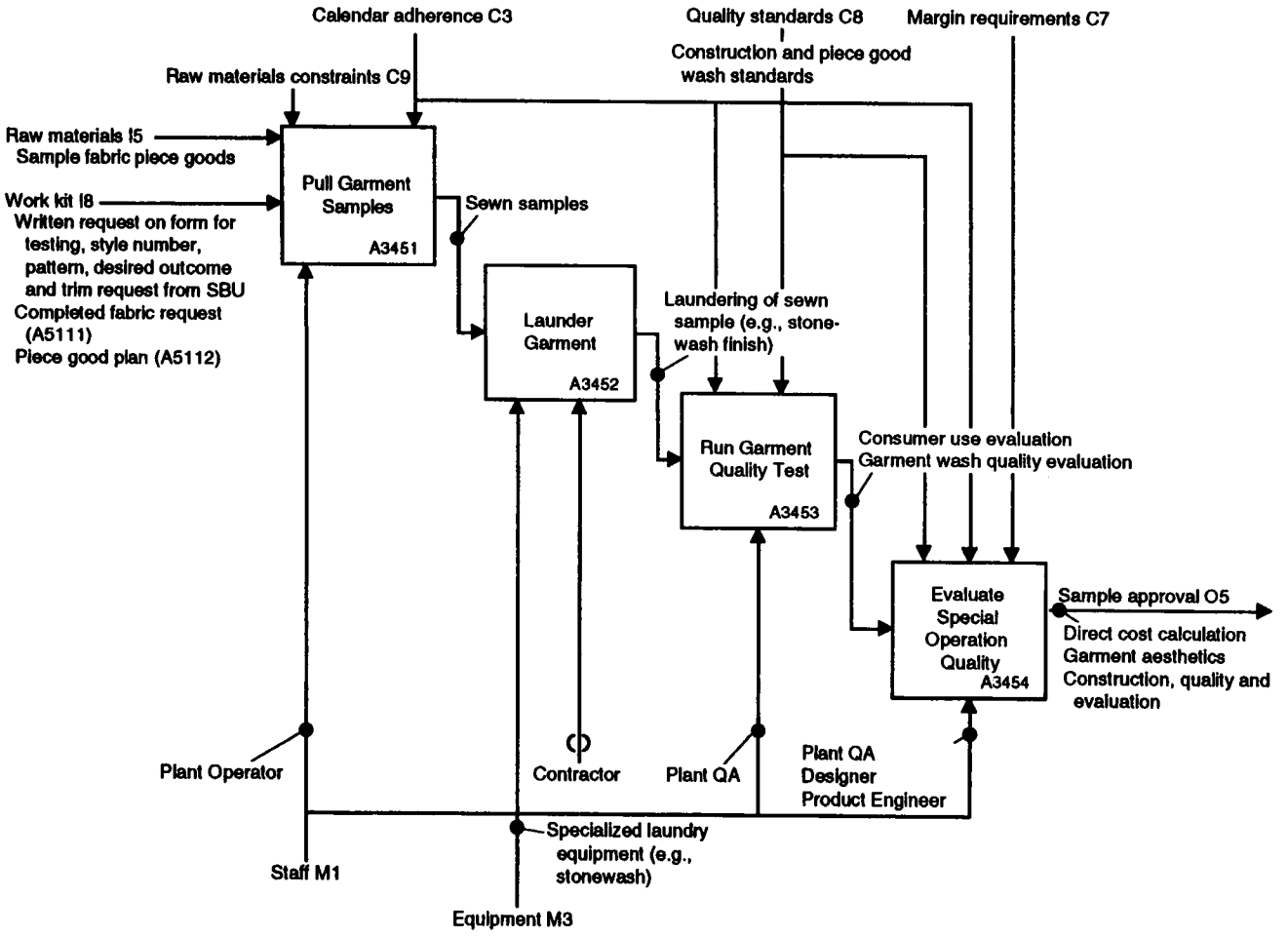
NODE: A343

Figure 75. Perform in-house special operations.



NODE: A344

Figure 76. Monitor outside special operations process.



NODE: A345

Figure 77. Perform outside special operation: laundering.

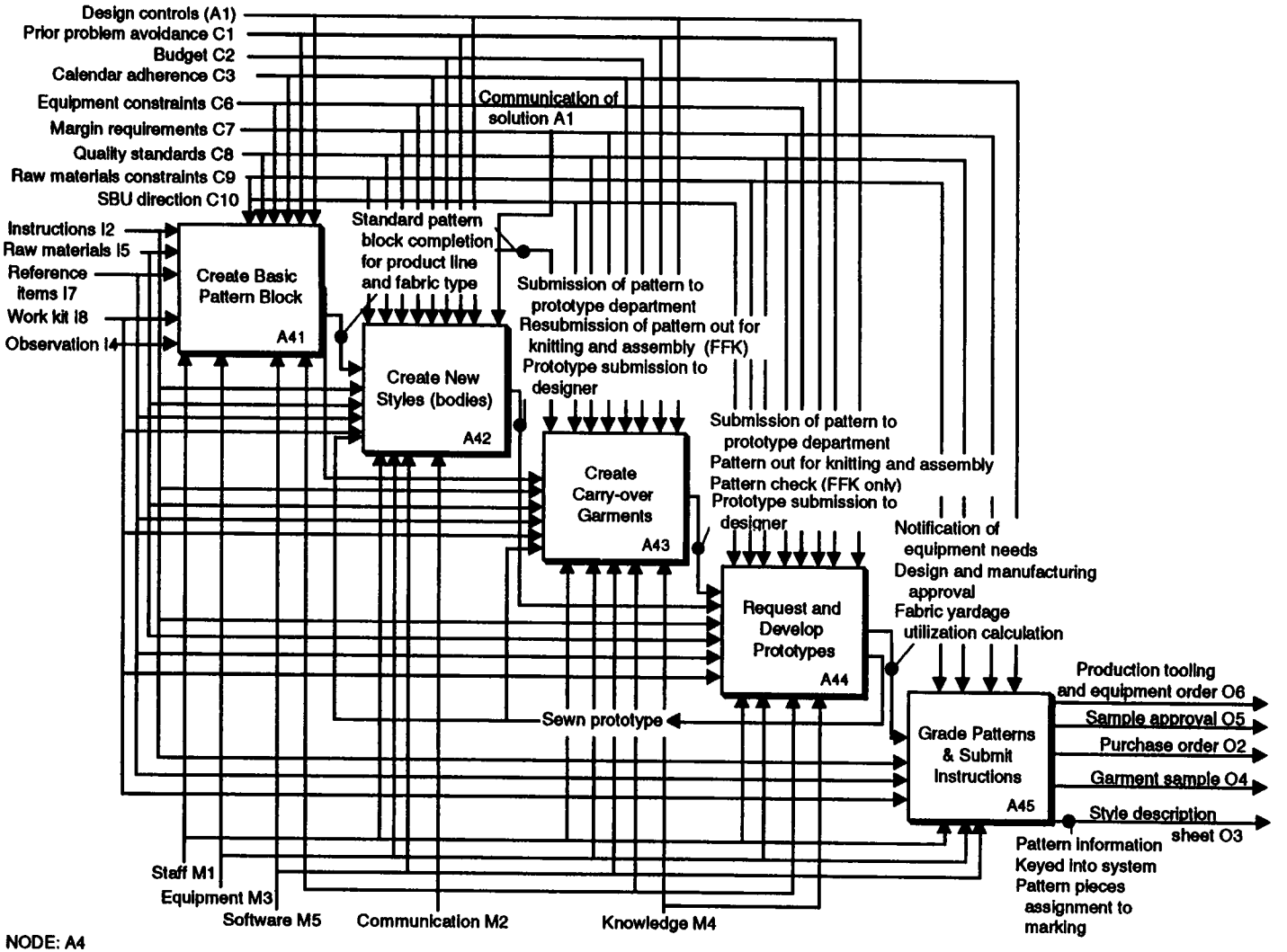
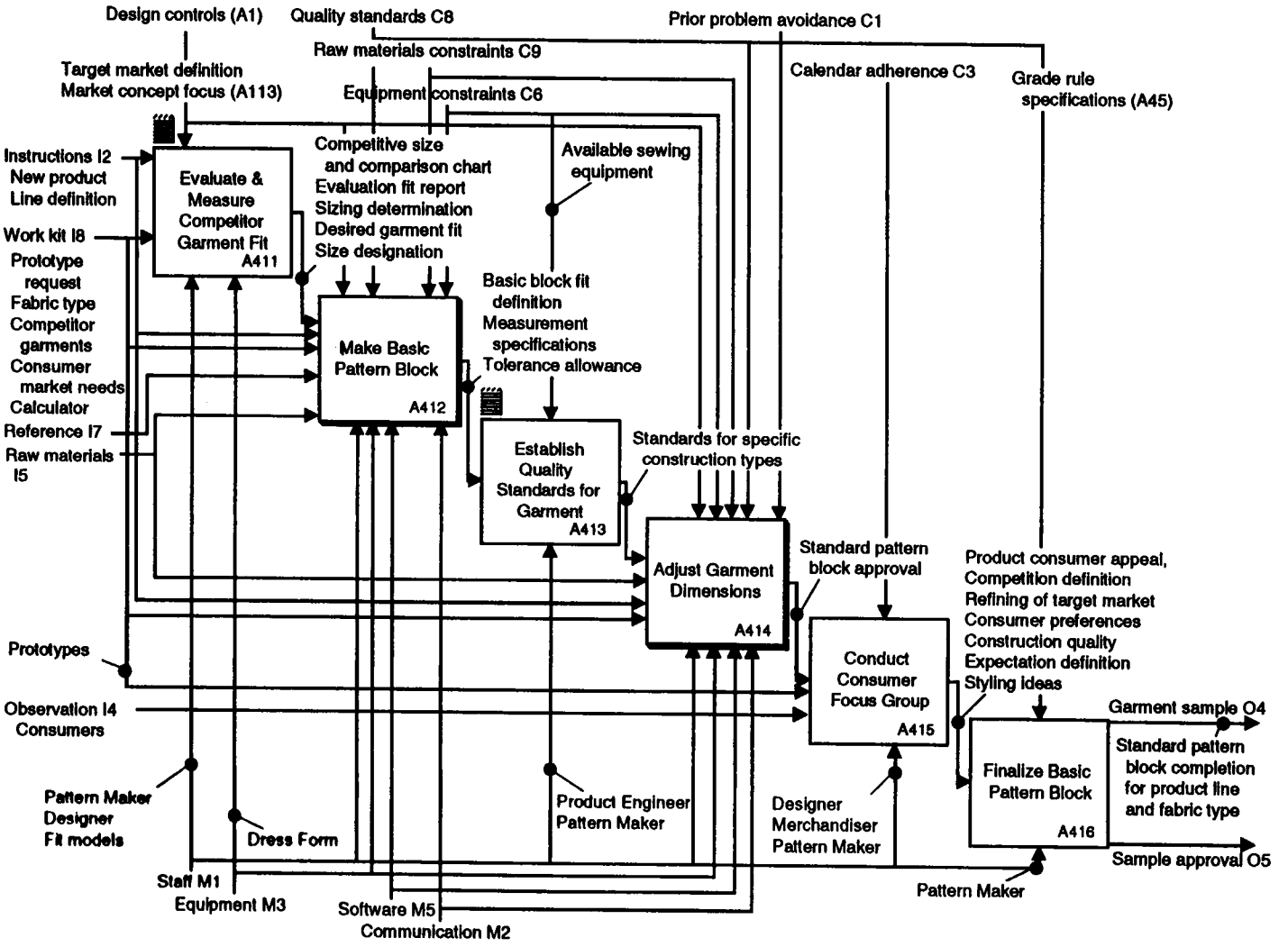
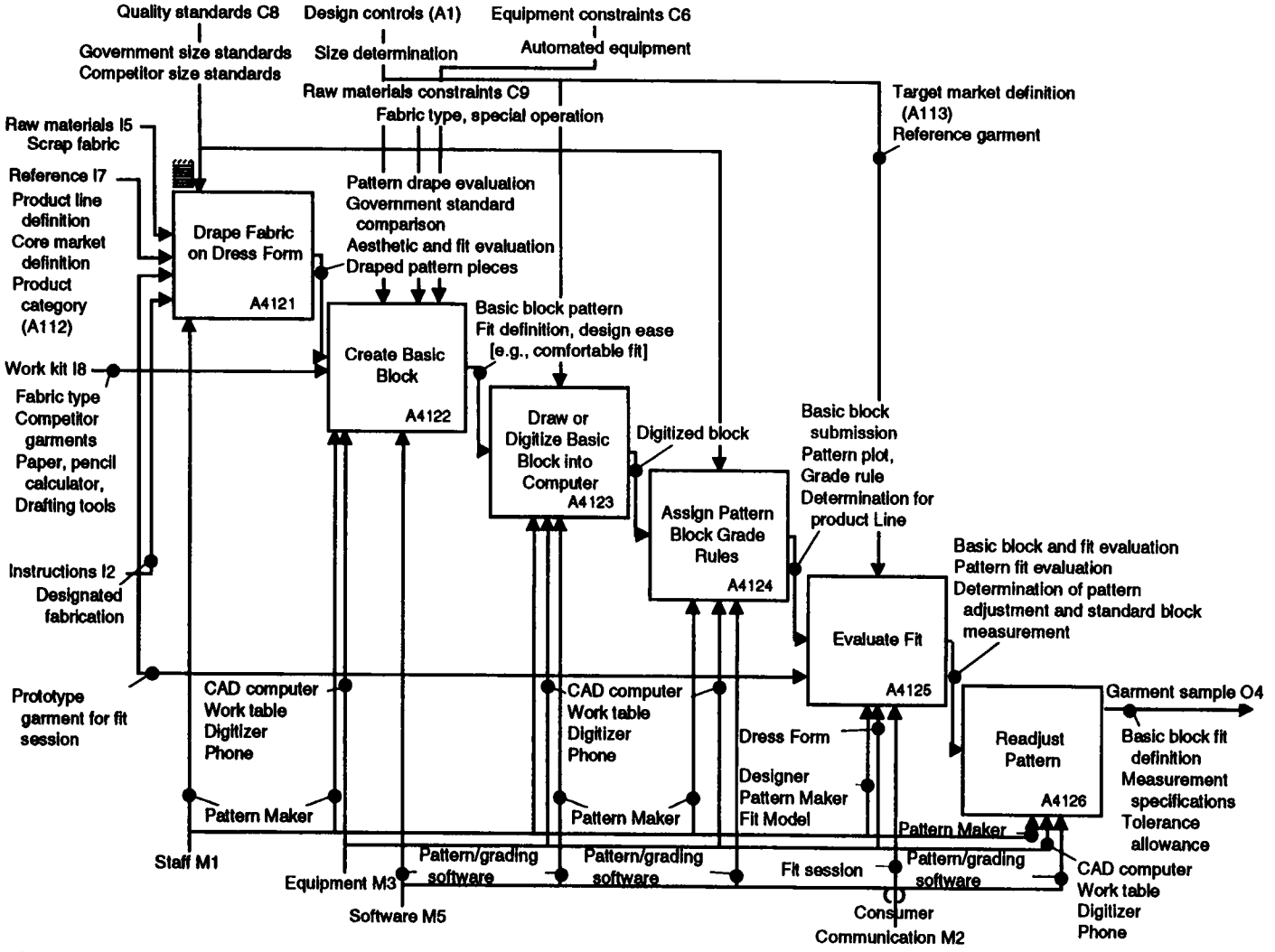


Figure 78. Create garment pattern and prototype.



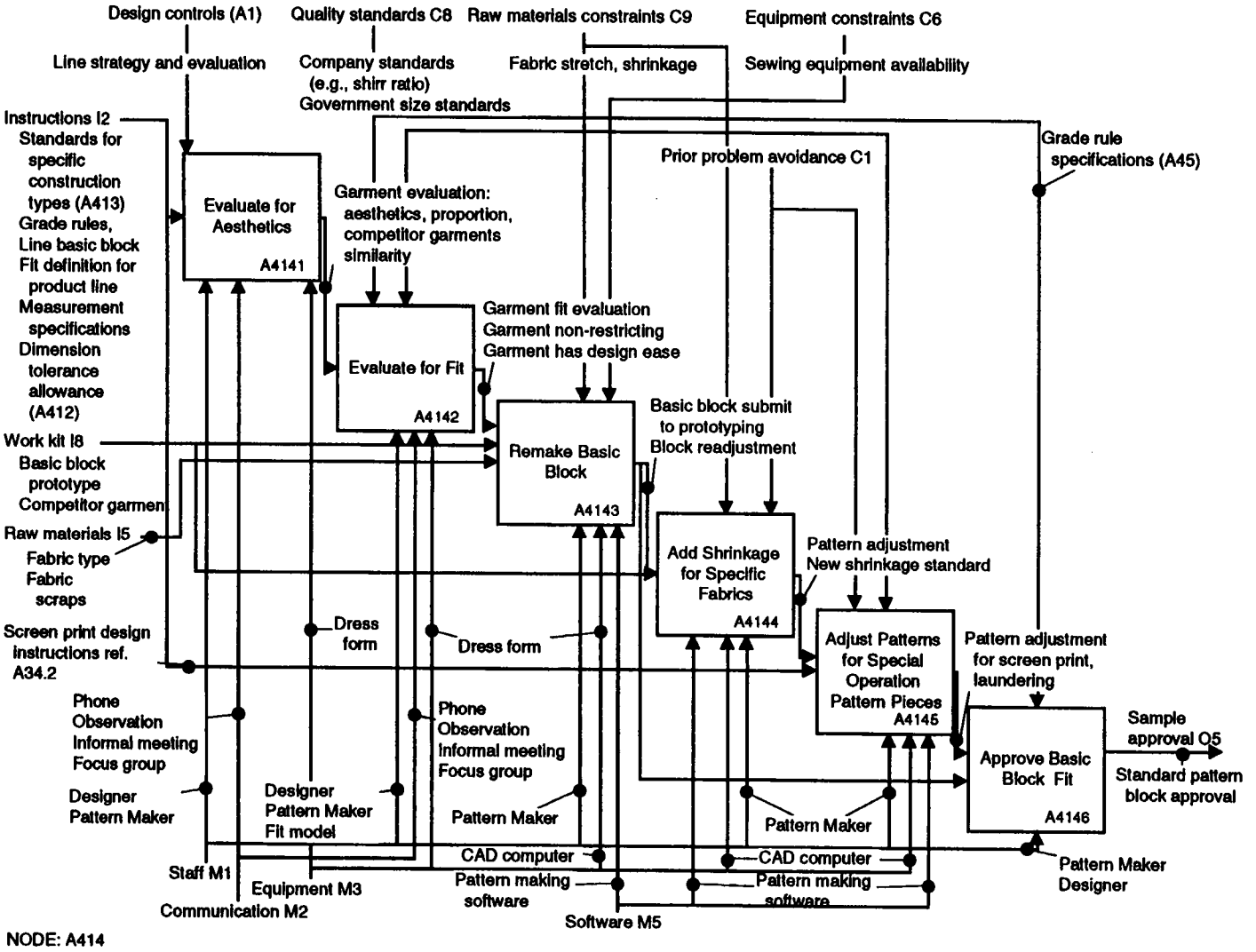
NODE: A41

Figure 79. Create basic pattern block.



NODE: A412

Figure 80. Make basic pattern block.



NODE: A414

Figure 81. Adjust garment dimensions.

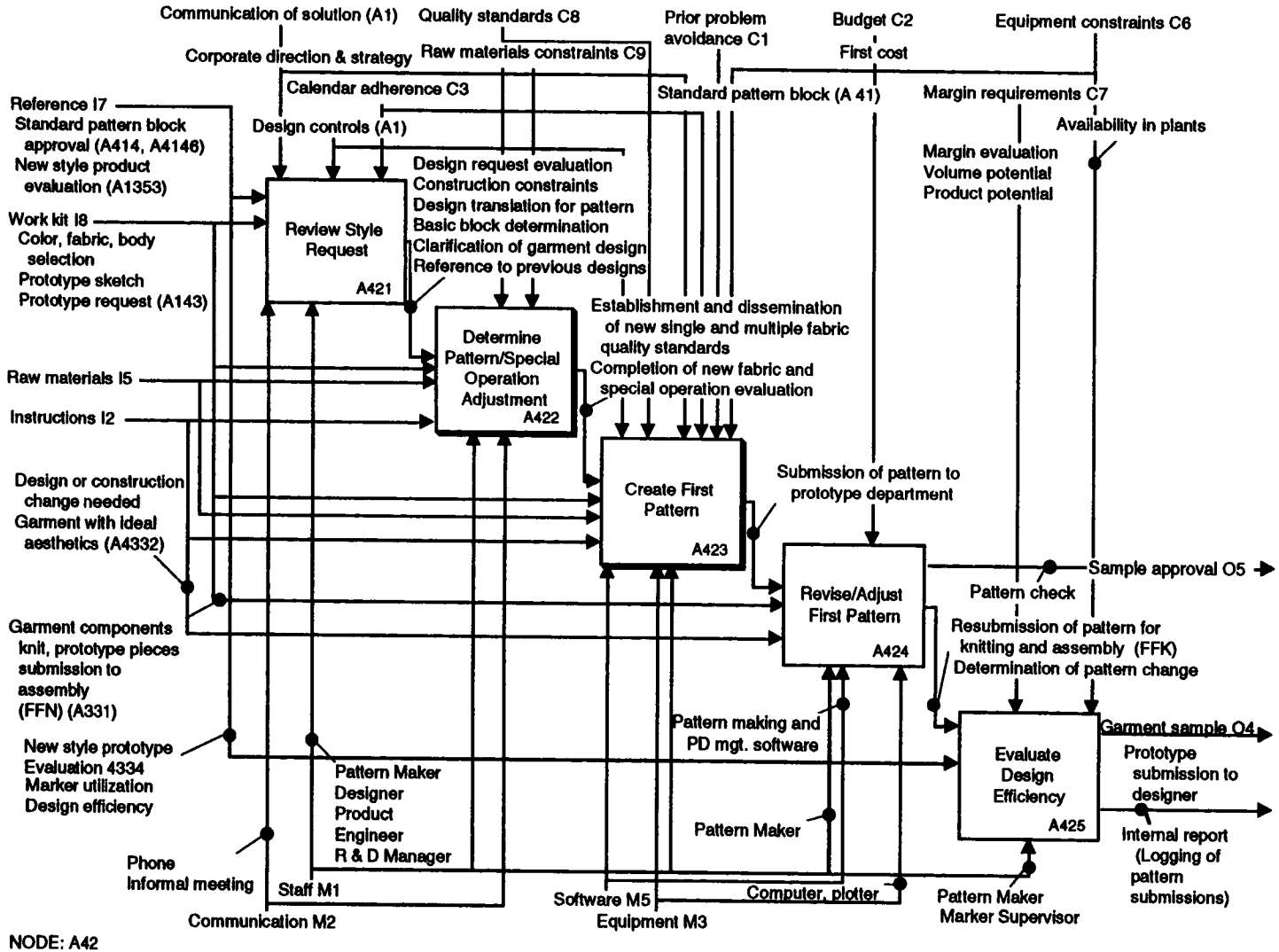
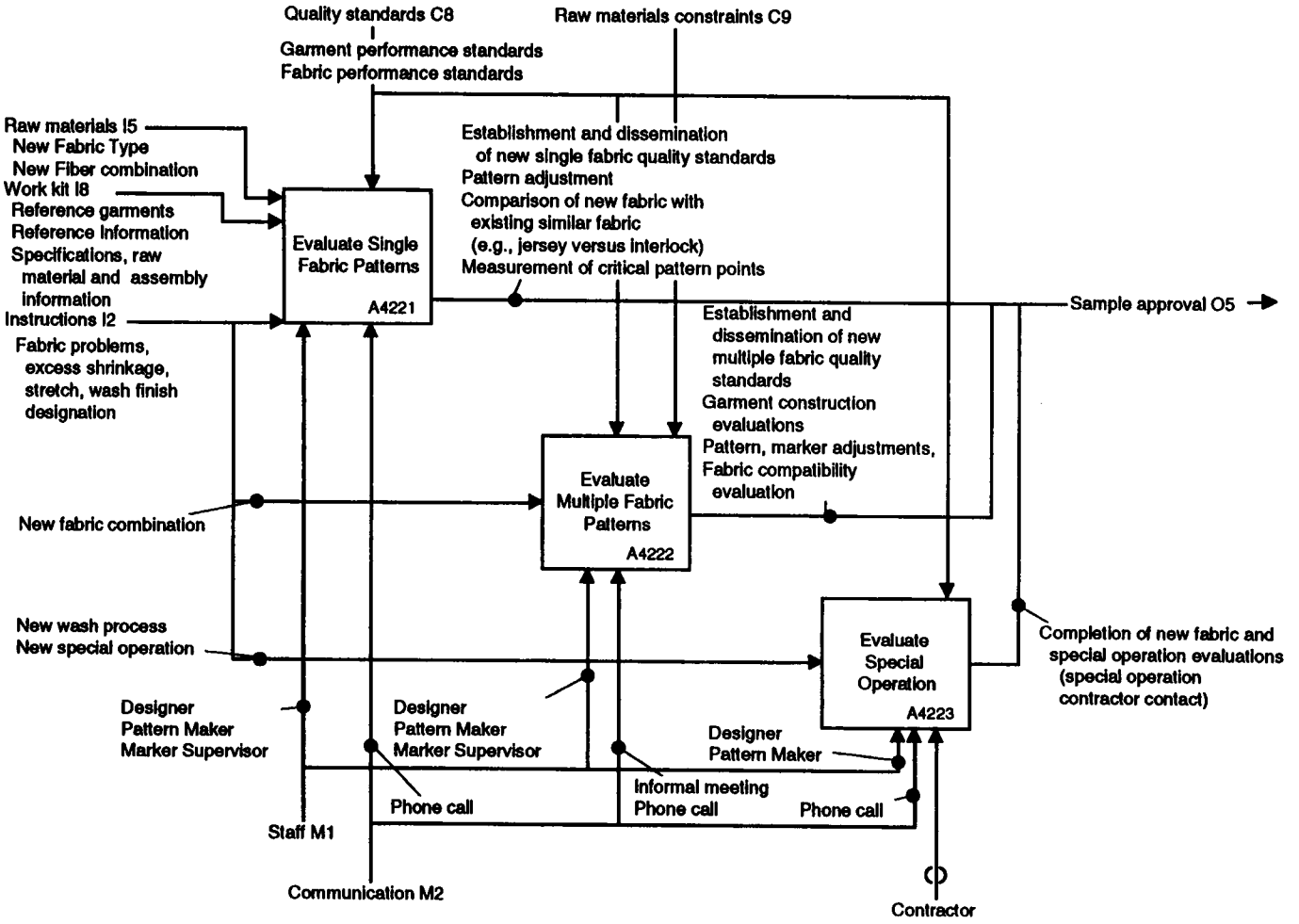
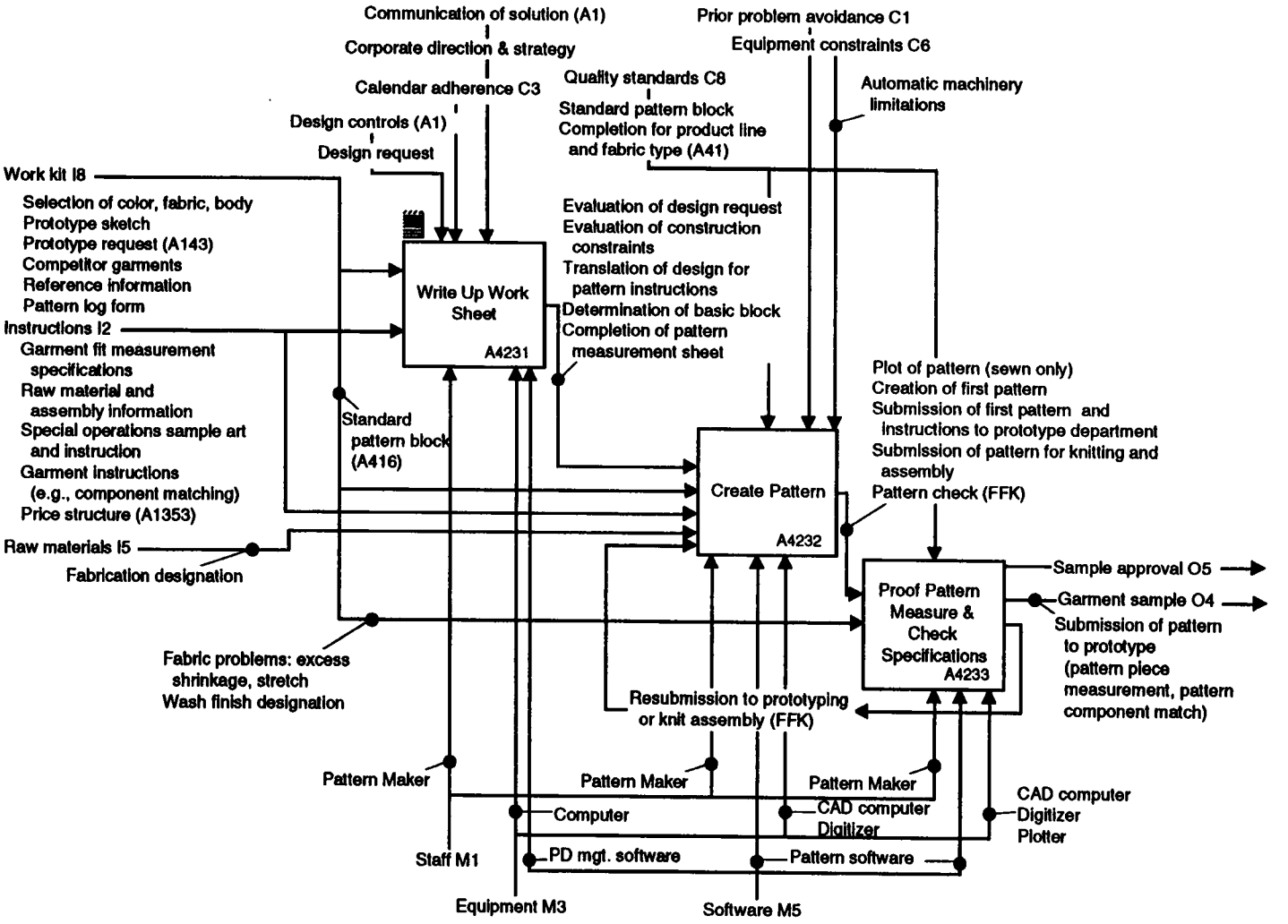


Figure 82. Create new styles bodies.



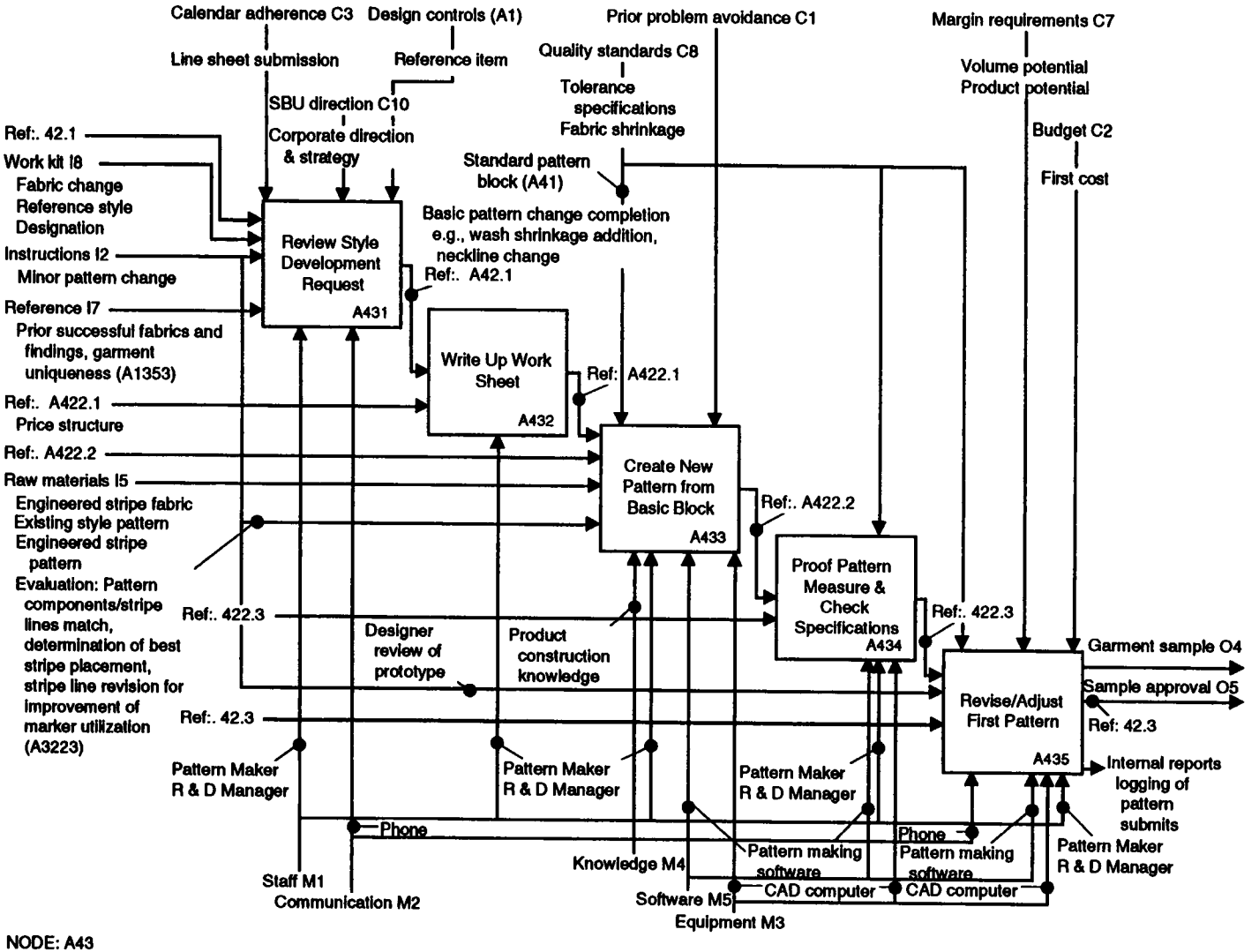
NODE: A422

Figure 83. Determine pattern/special operation adjustment.



NODE: A423

Figure 84. Create first pattern.



NODE: A43

Figure 85. Create carry-over garments.

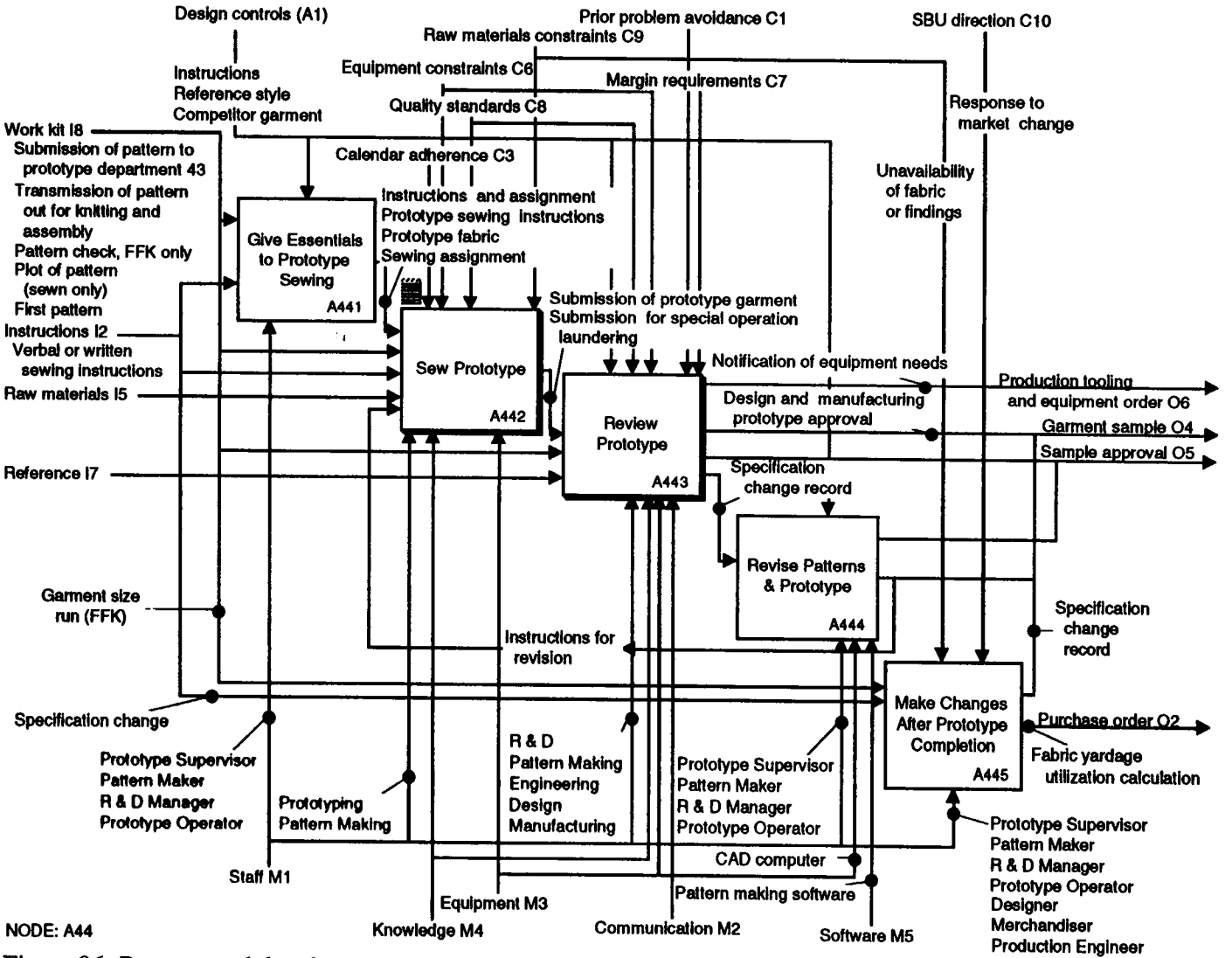


Figure 86. Request and develop prototypes.

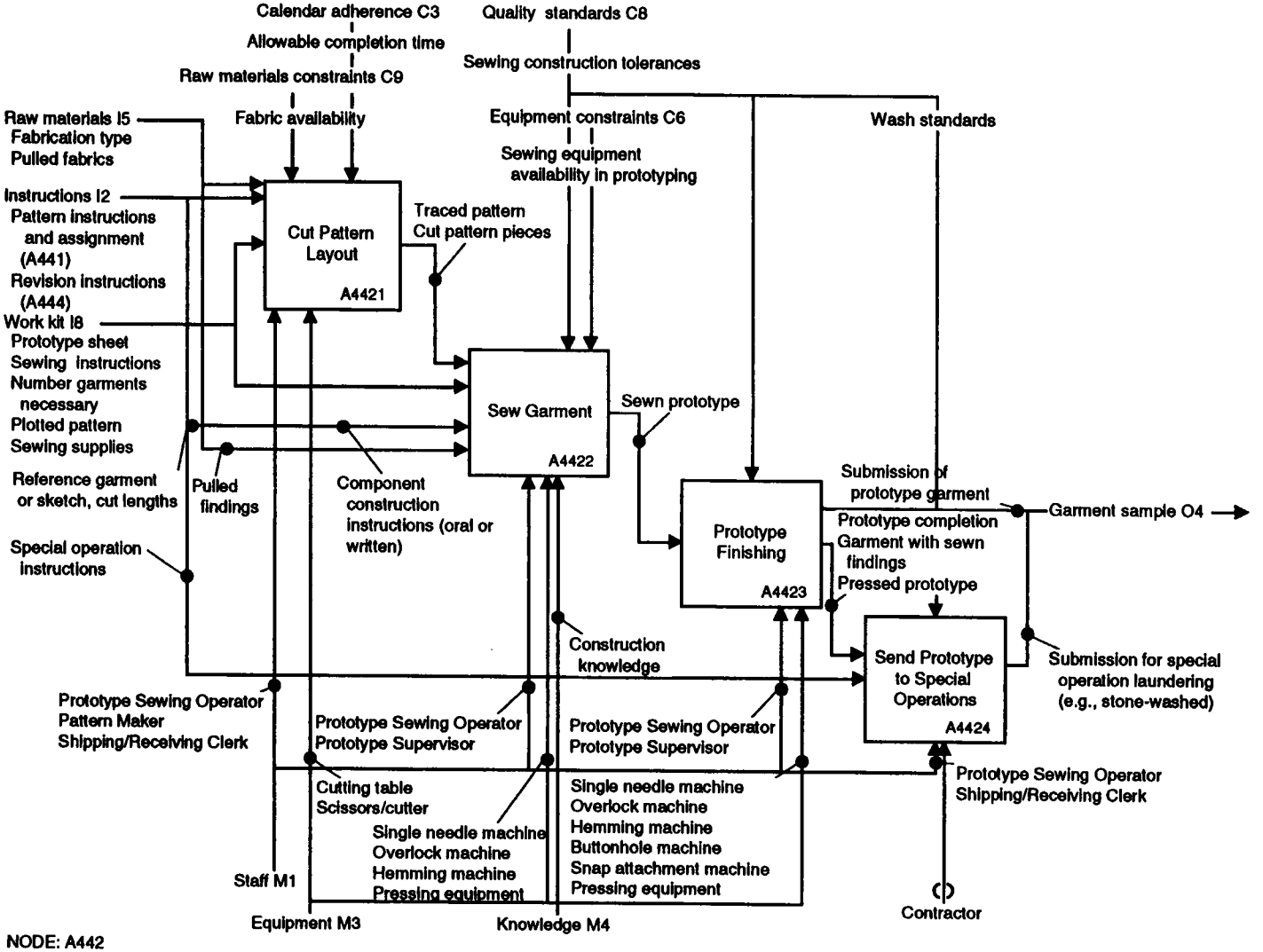
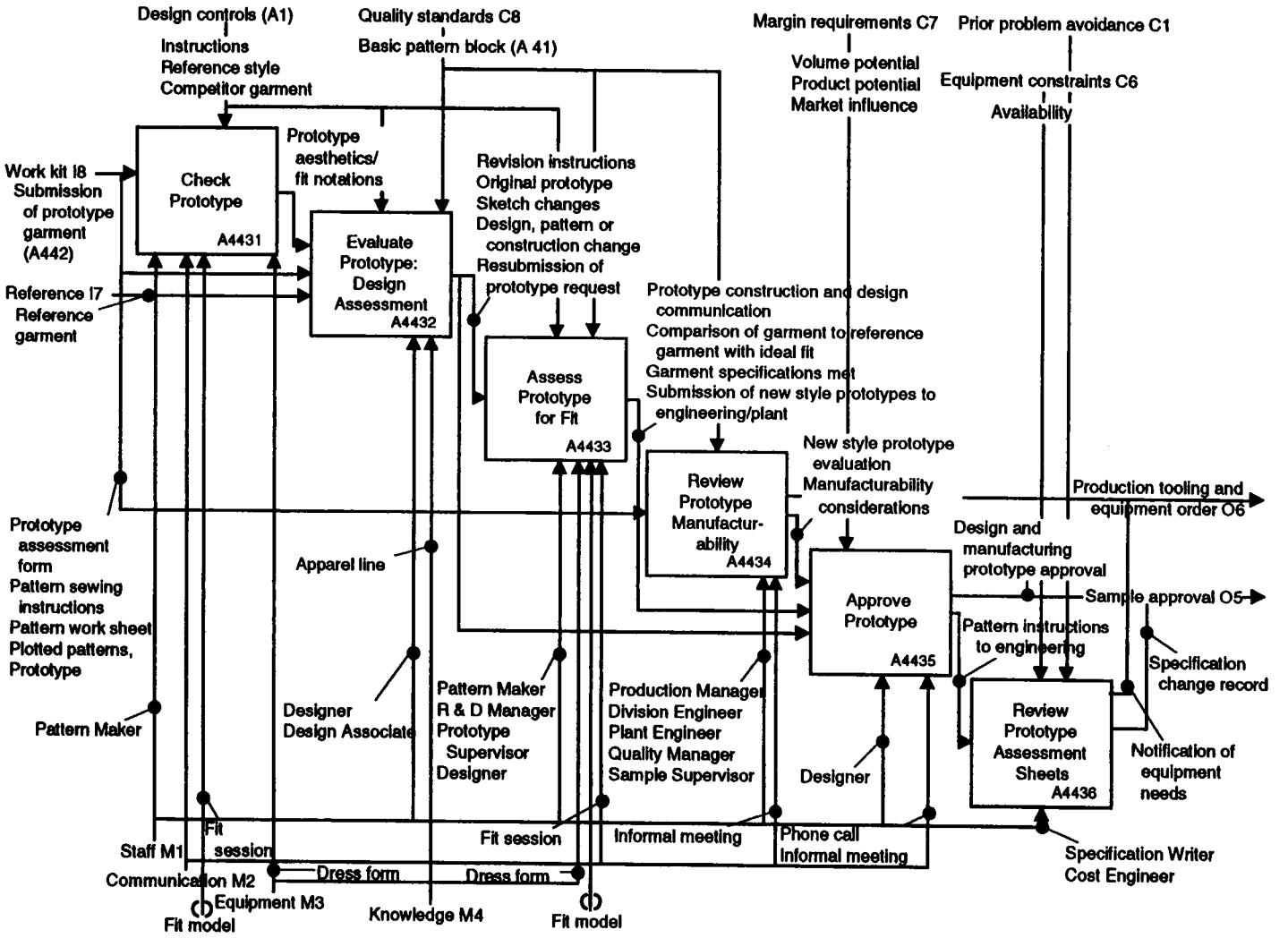
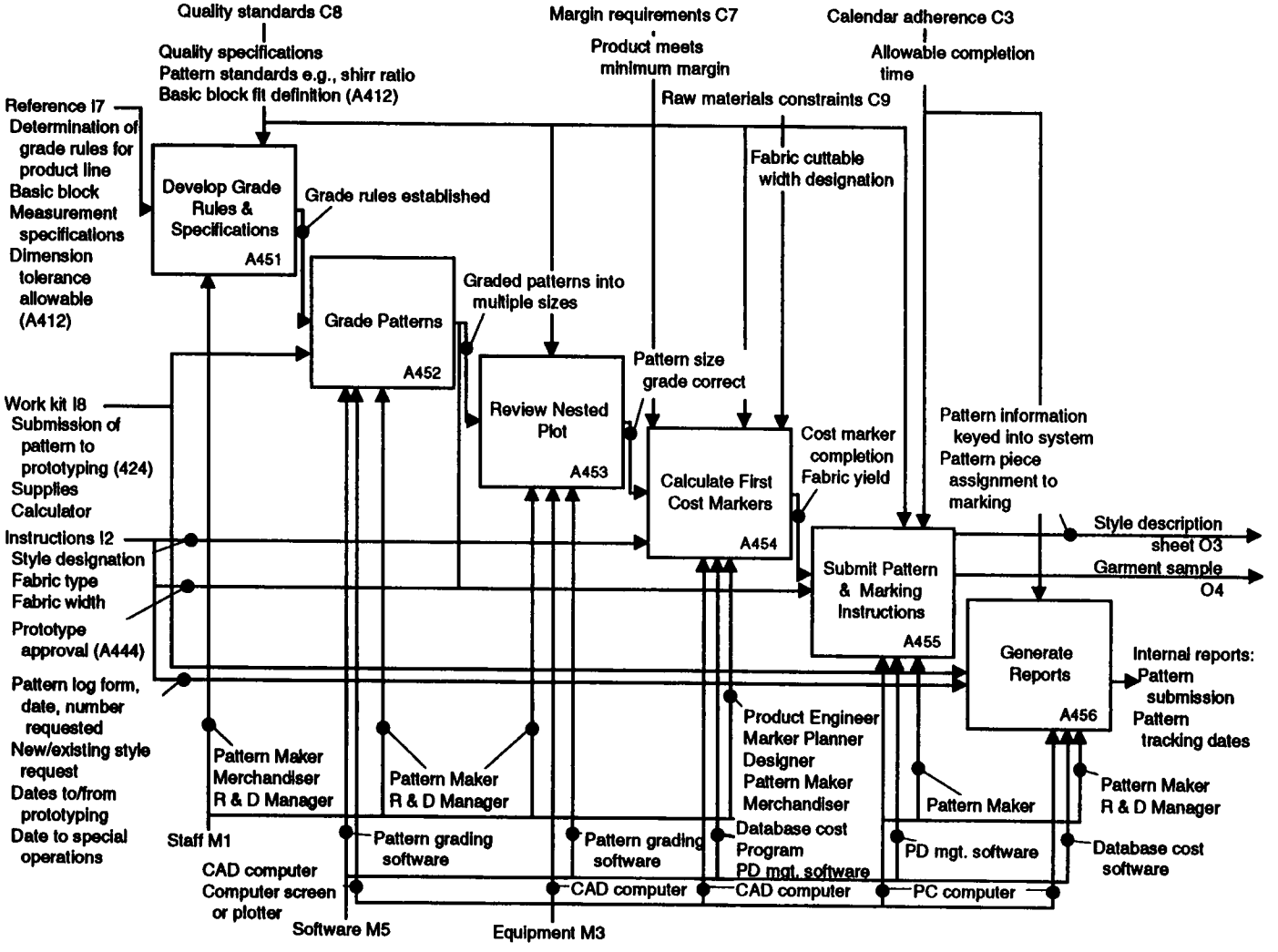


Figure 87. Sew prototype.



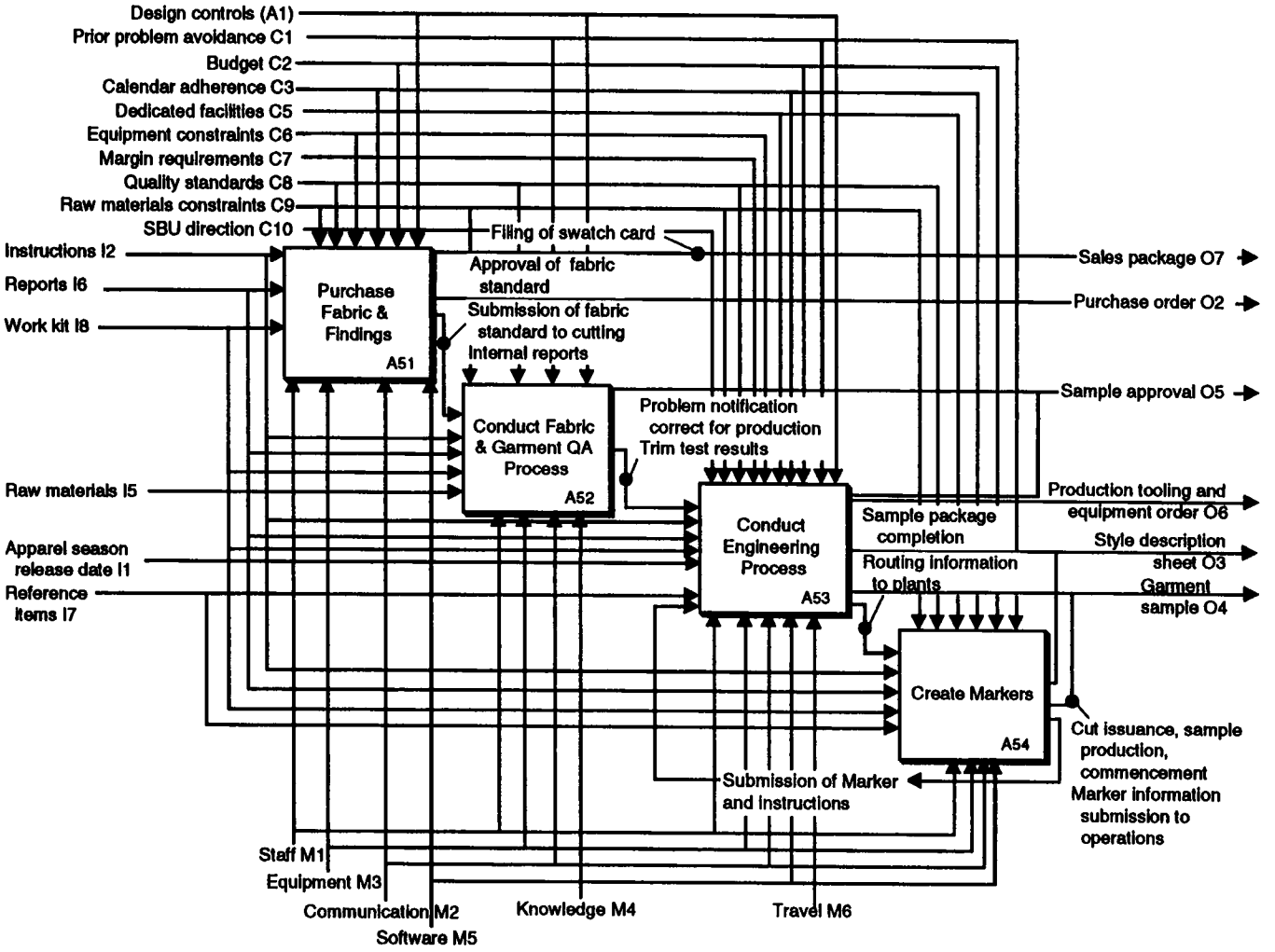
NODE: A443

Figure 88. Review prototype.



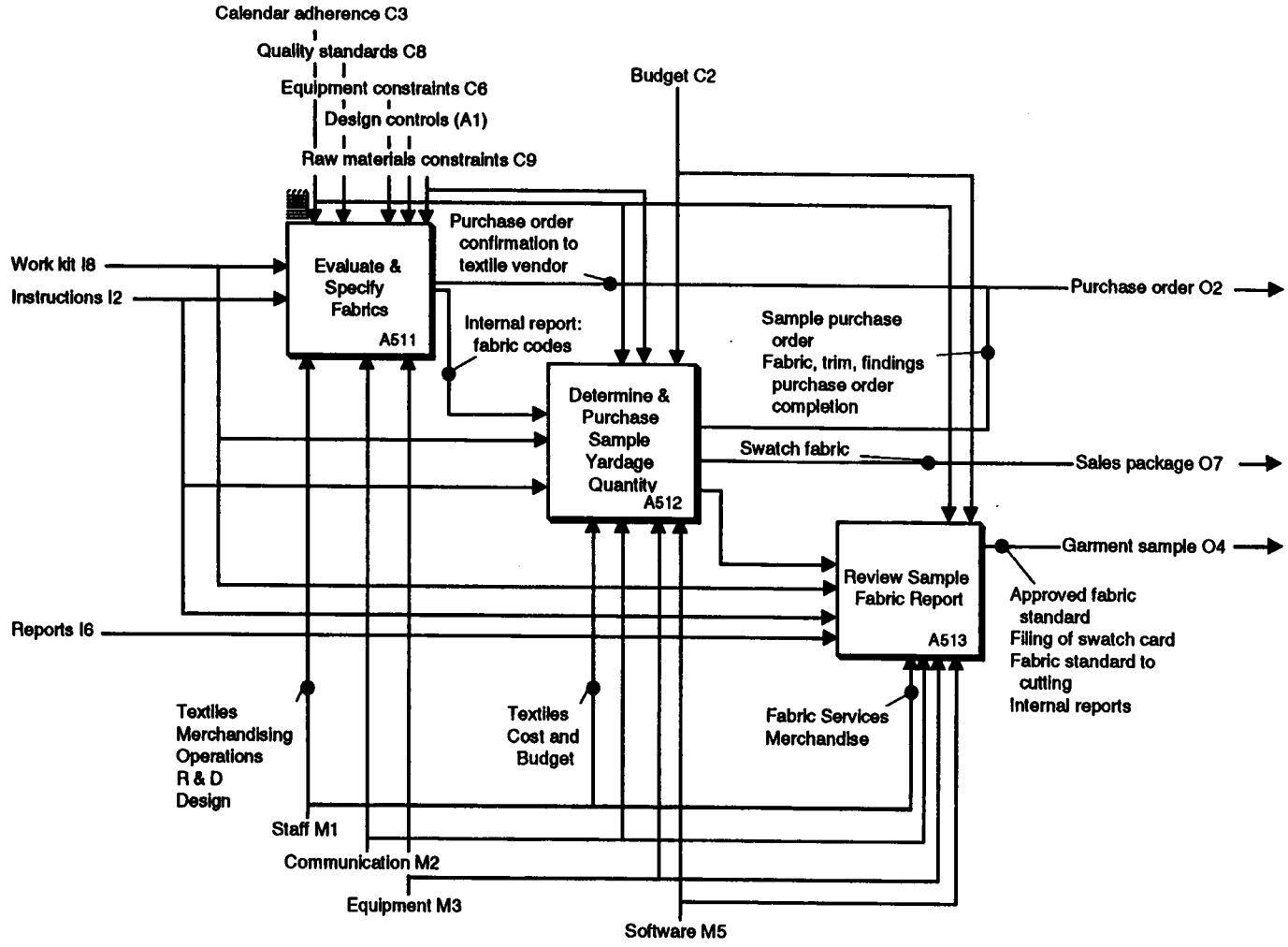
NODE: A45

Figure 89. Grade patterns and submit instructions.



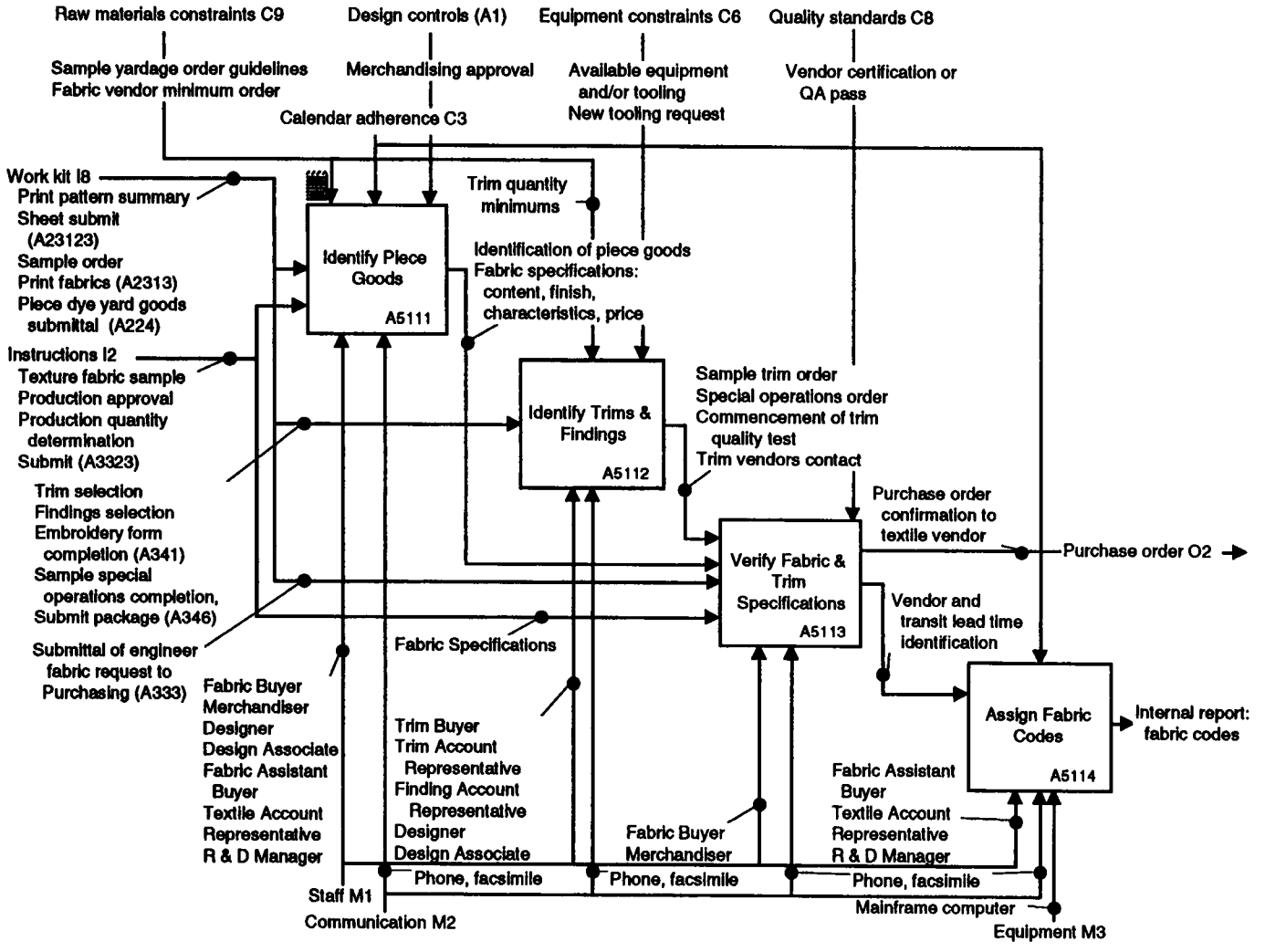
NODE: A5

Figure 90. Set production specifications.



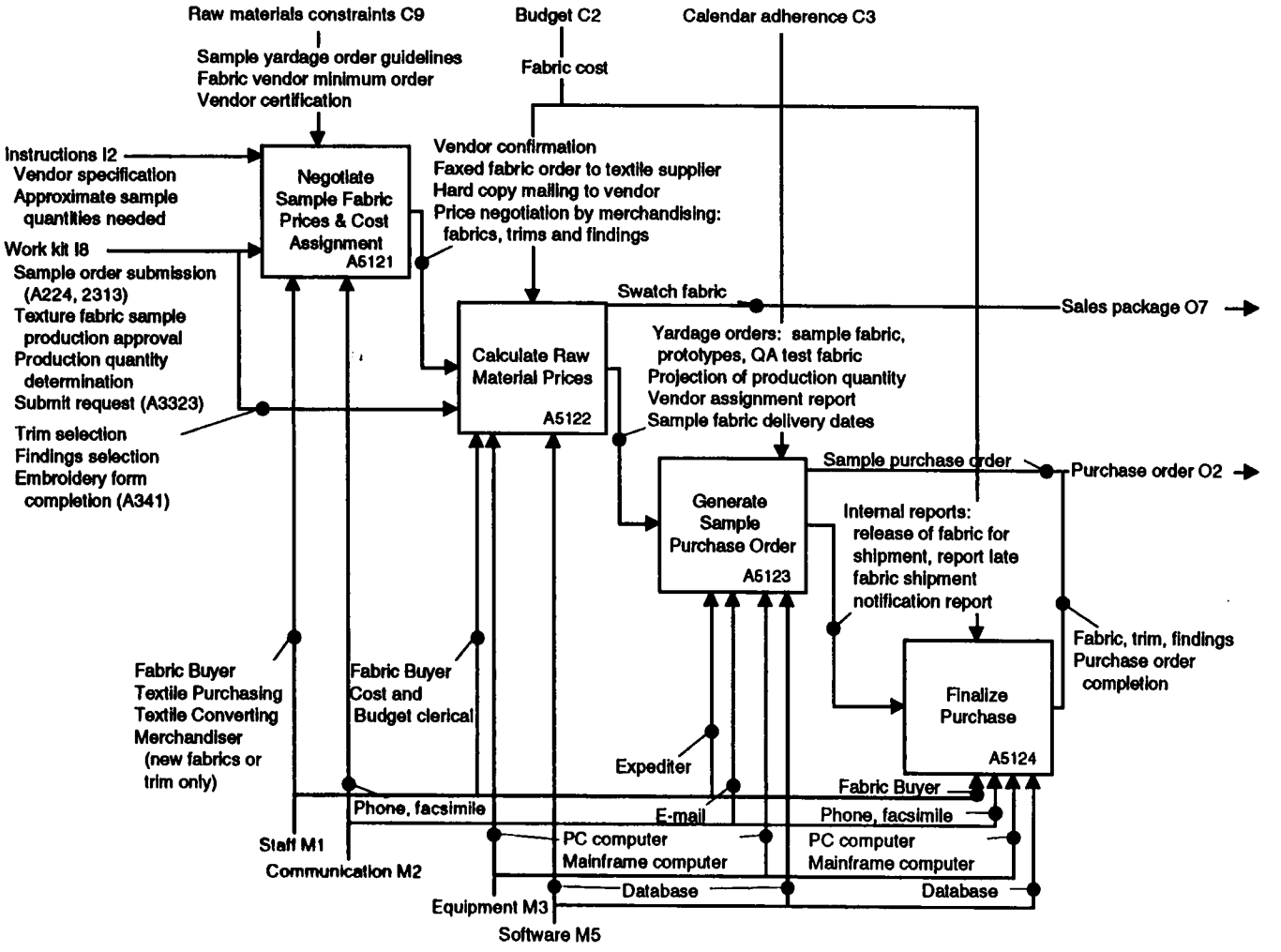
NODE: A51

Figure 91. Purchase fabric and findings.



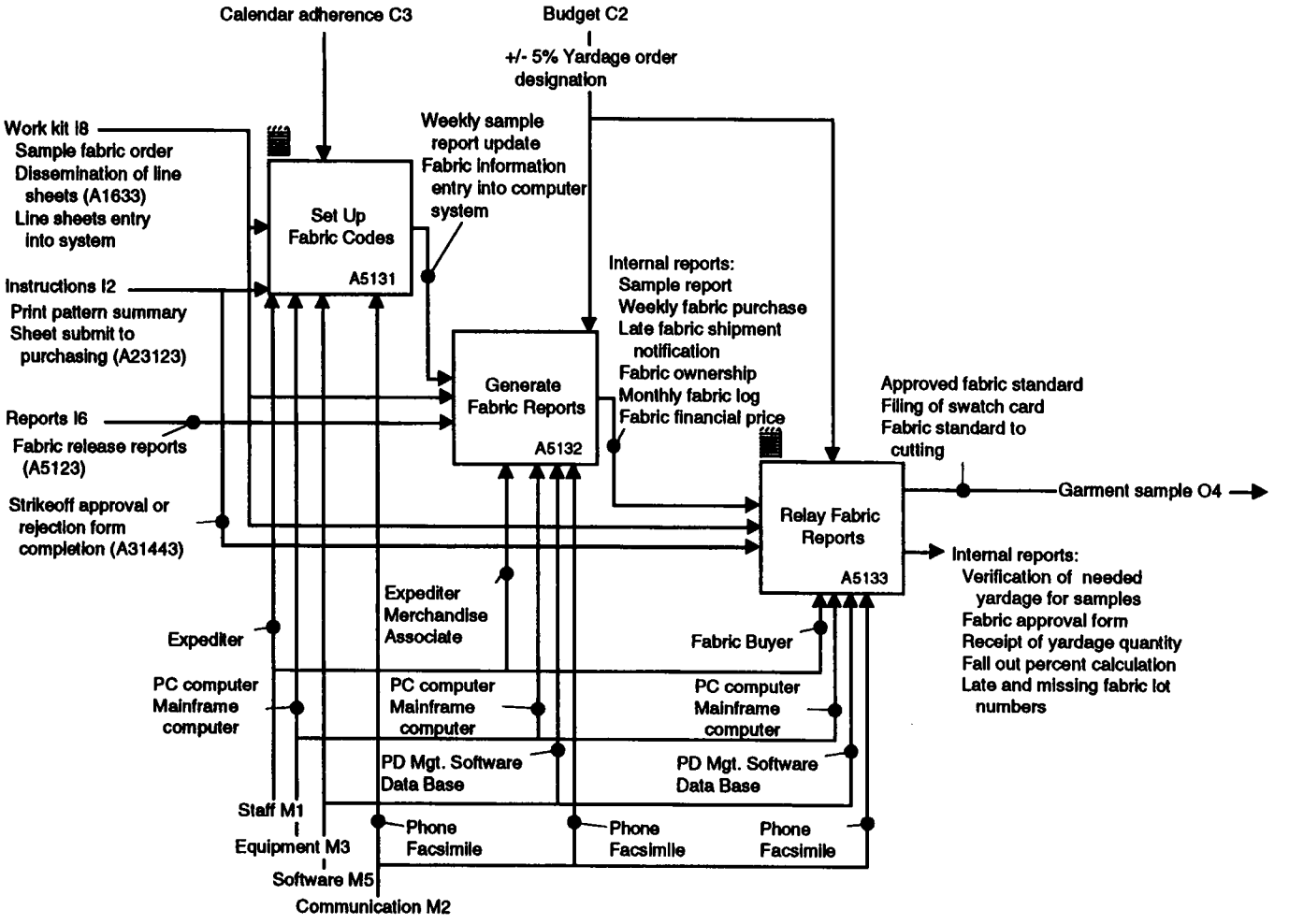
NODE: A511

Figure 92. Evaluate and specify fabrics.



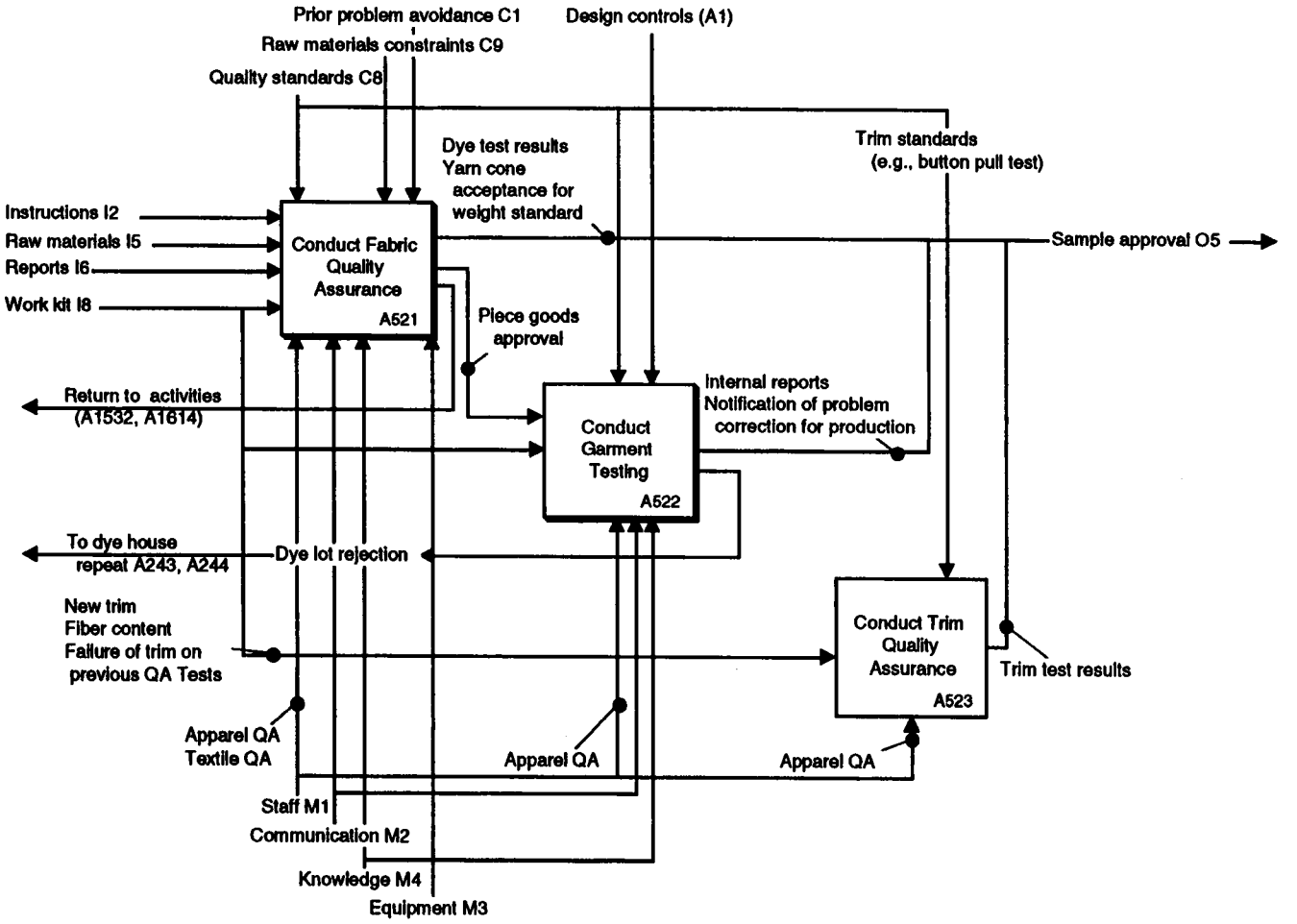
NODE: 512

Figure 93. Determine and purchase sample yardage quantity.



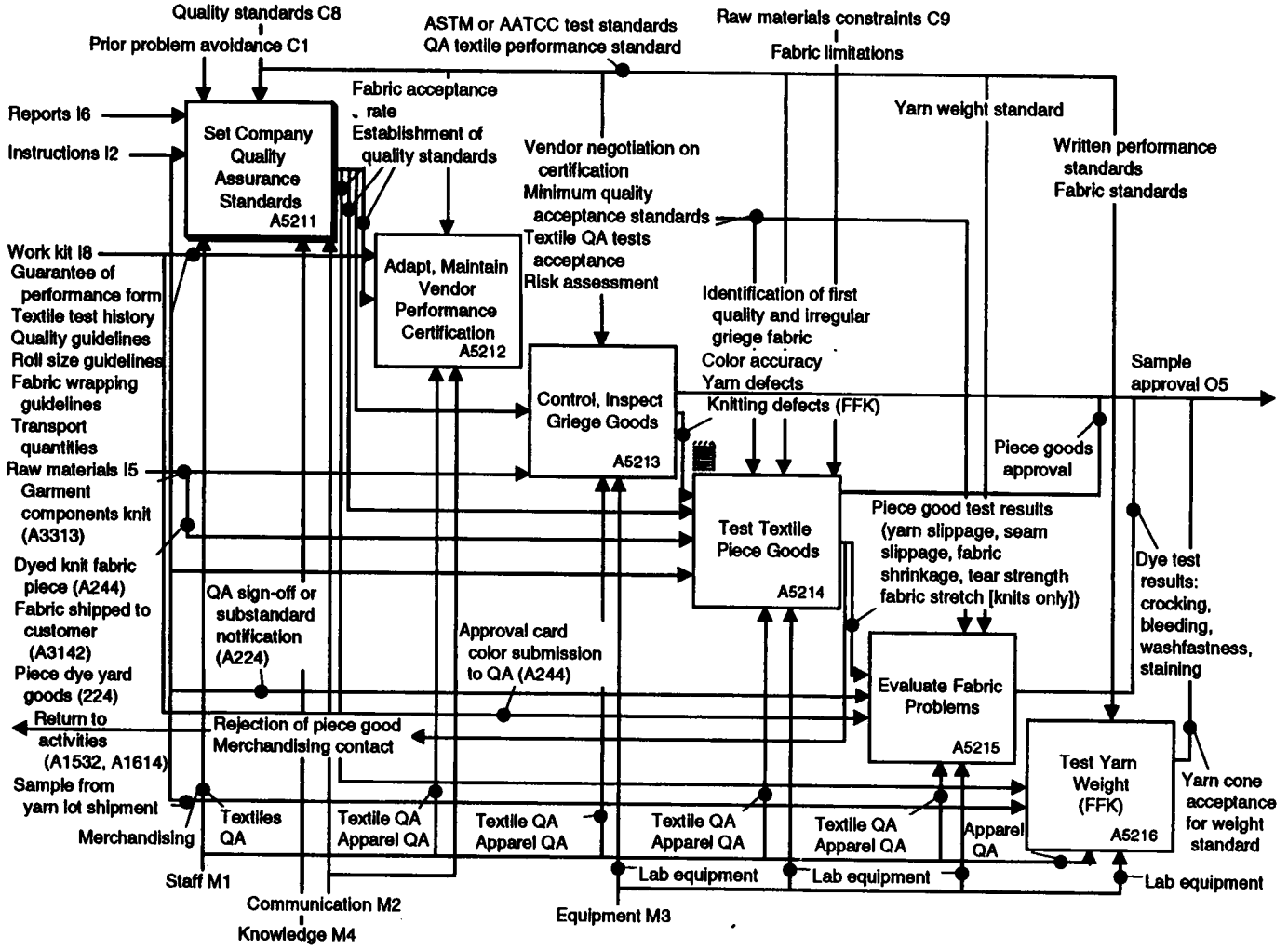
NODE: A513

Figure 94. Review sample fabric report.



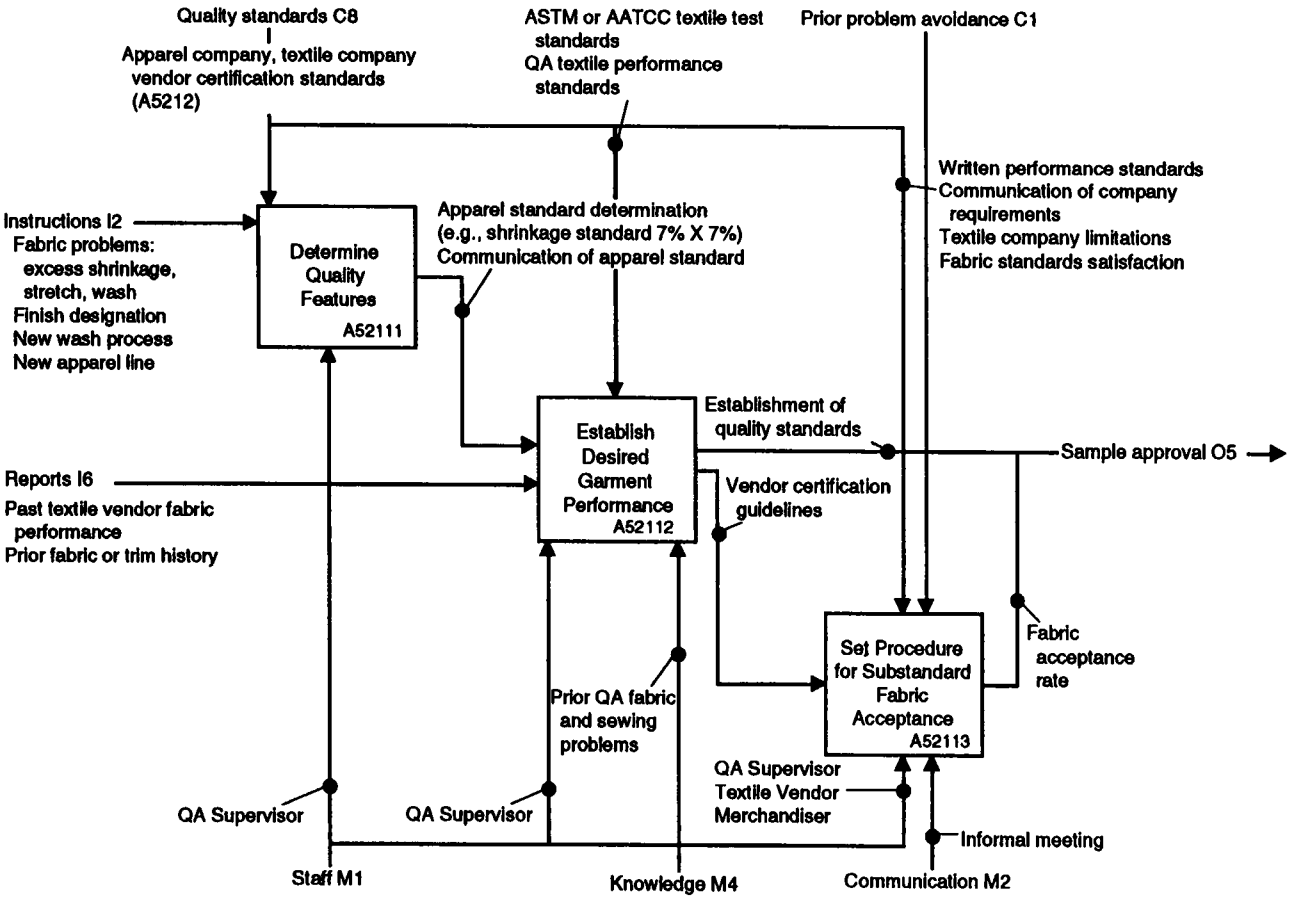
NODE: A52

Figure 95. Conduct fabric and garment QA process.



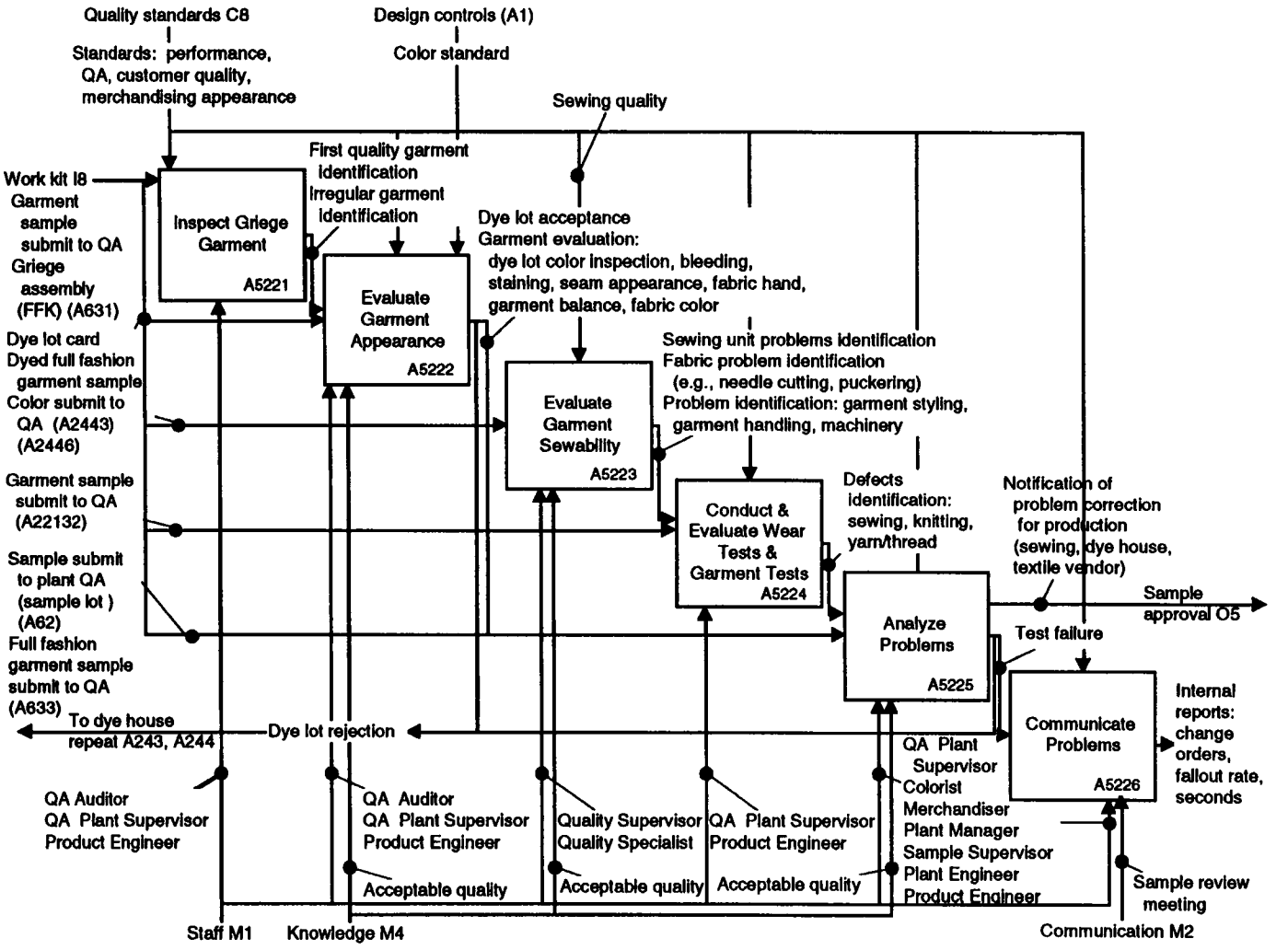
NODE: A521

Figure 96. Conduct fabric quality assurance.



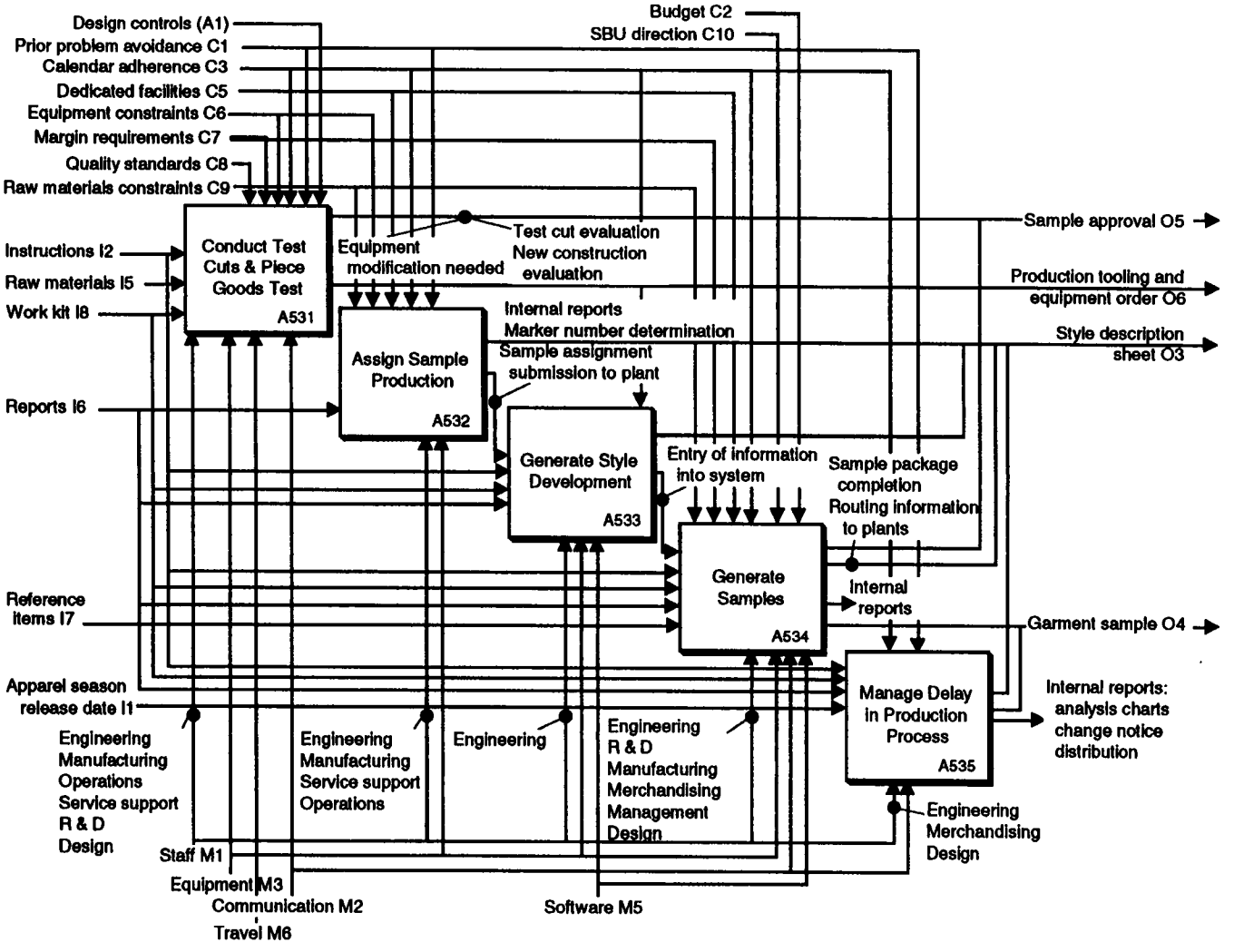
NODE: A5211

Figure 97. Set company quality assurance standards.



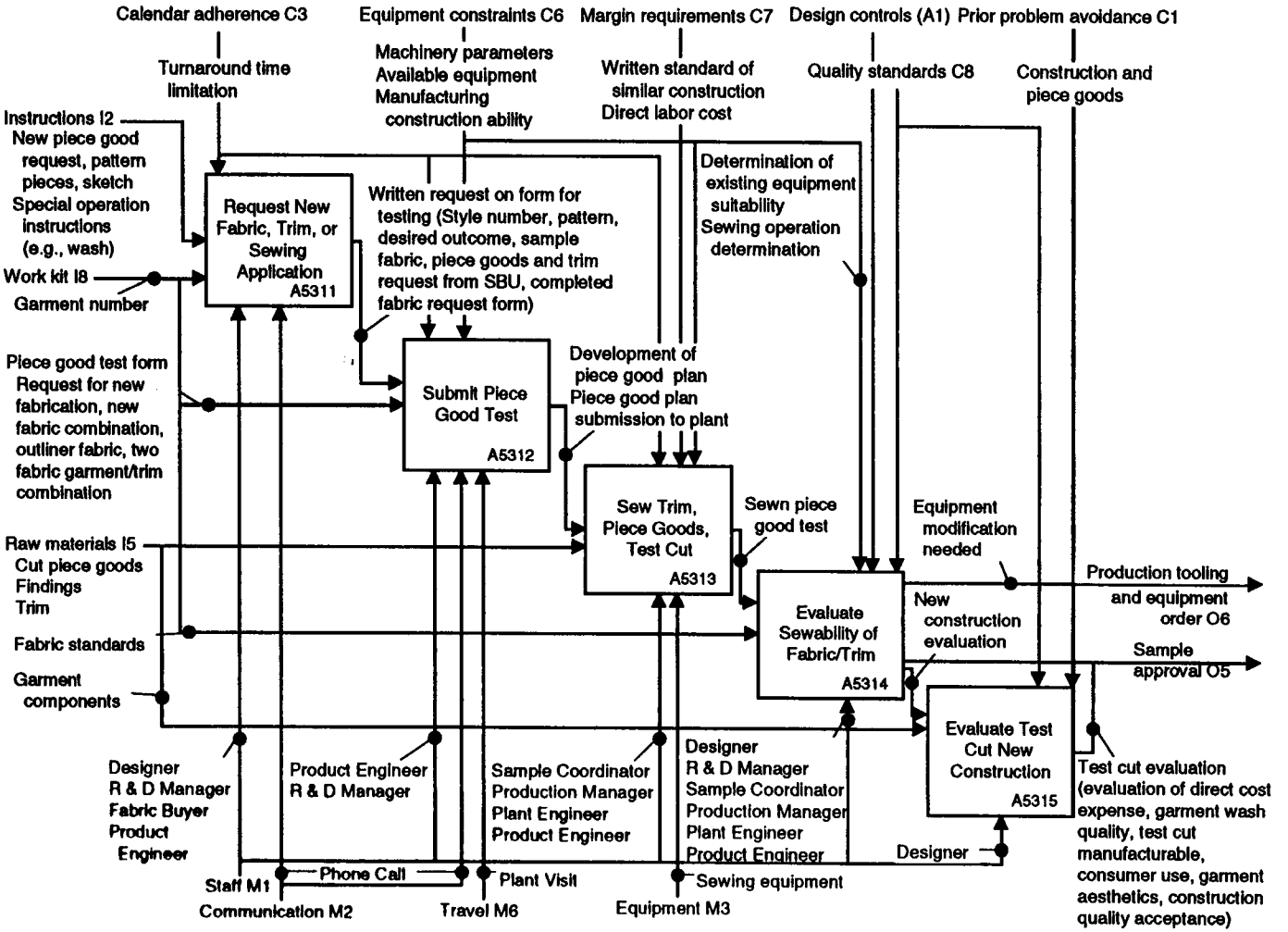
NODE: A522

Figure 98. Conduct garment testing.



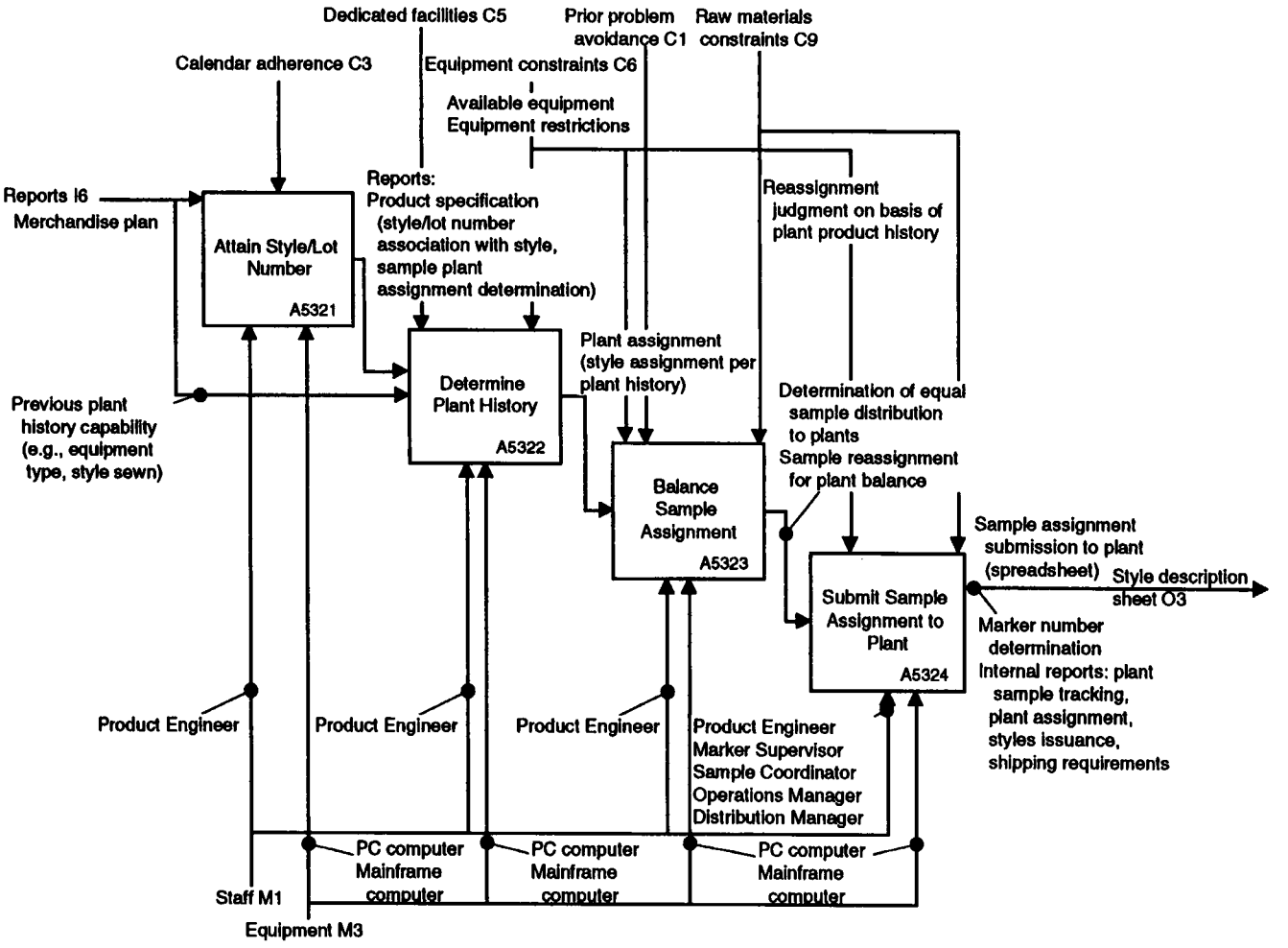
NODE: 53

Figure 99. Conduct engineering process.



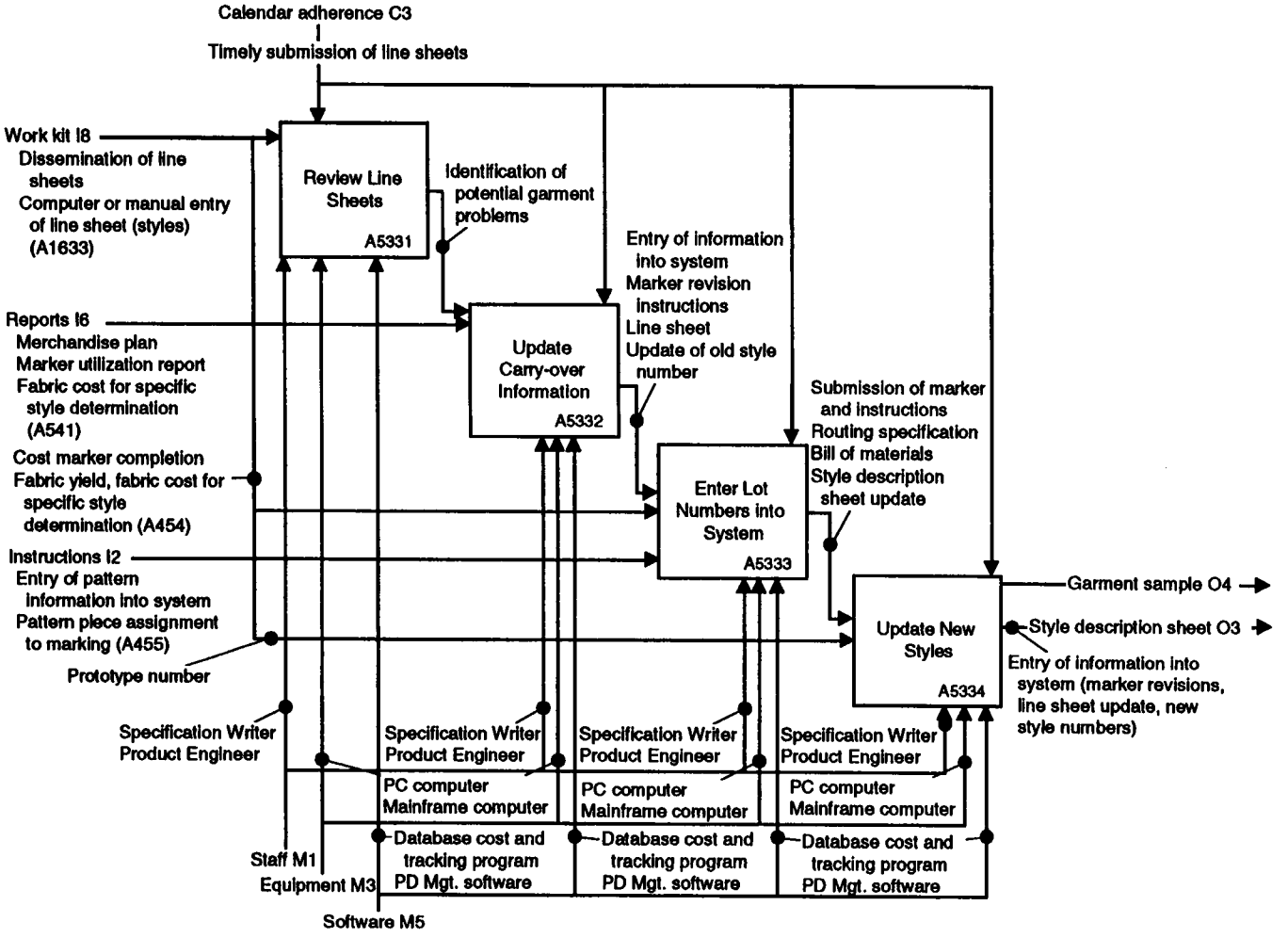
NODE: A531

Figure 100. Conduct test cuts and piece goods test.



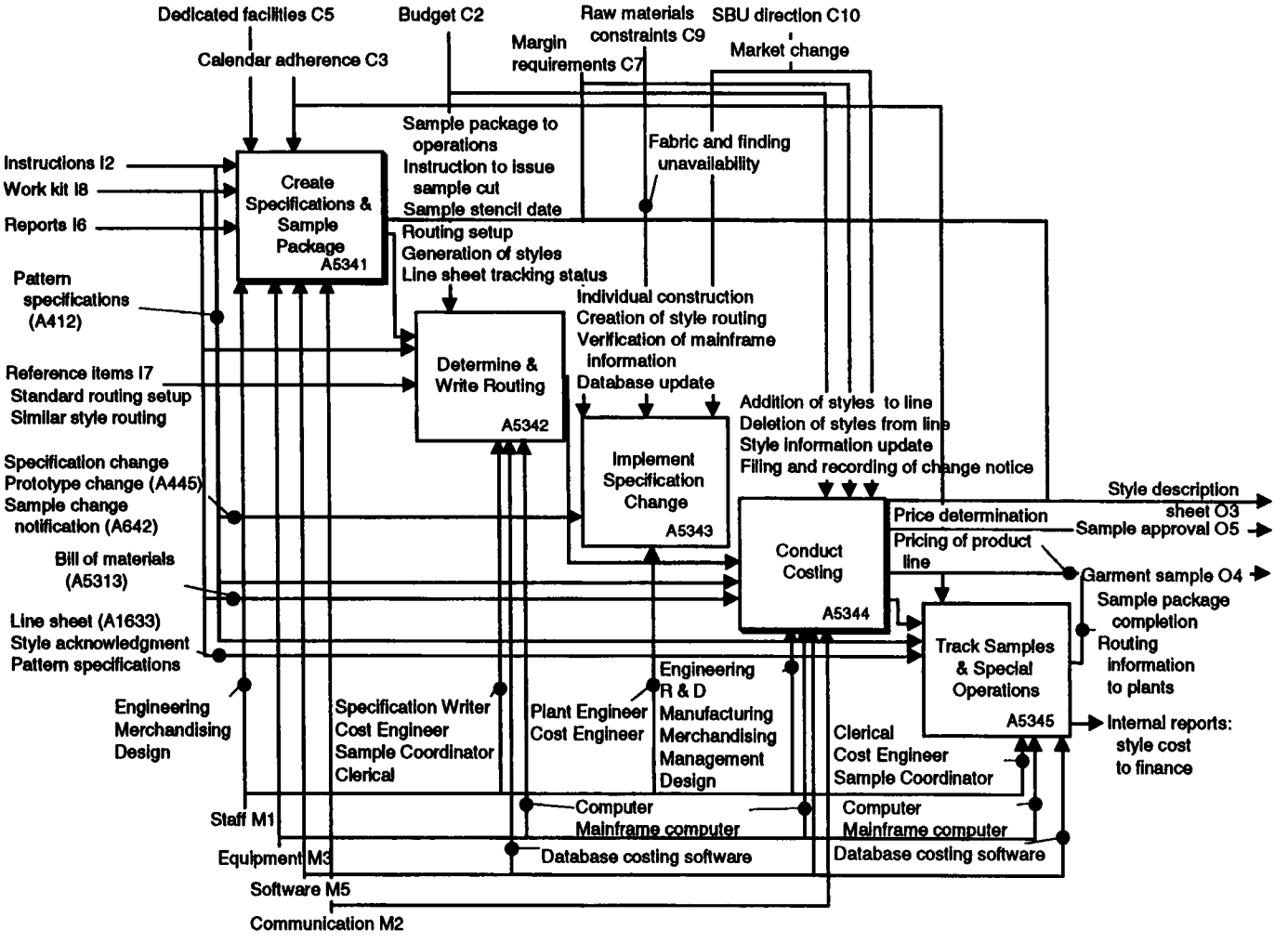
NODE: 532

Figure 101. Assign sample production.



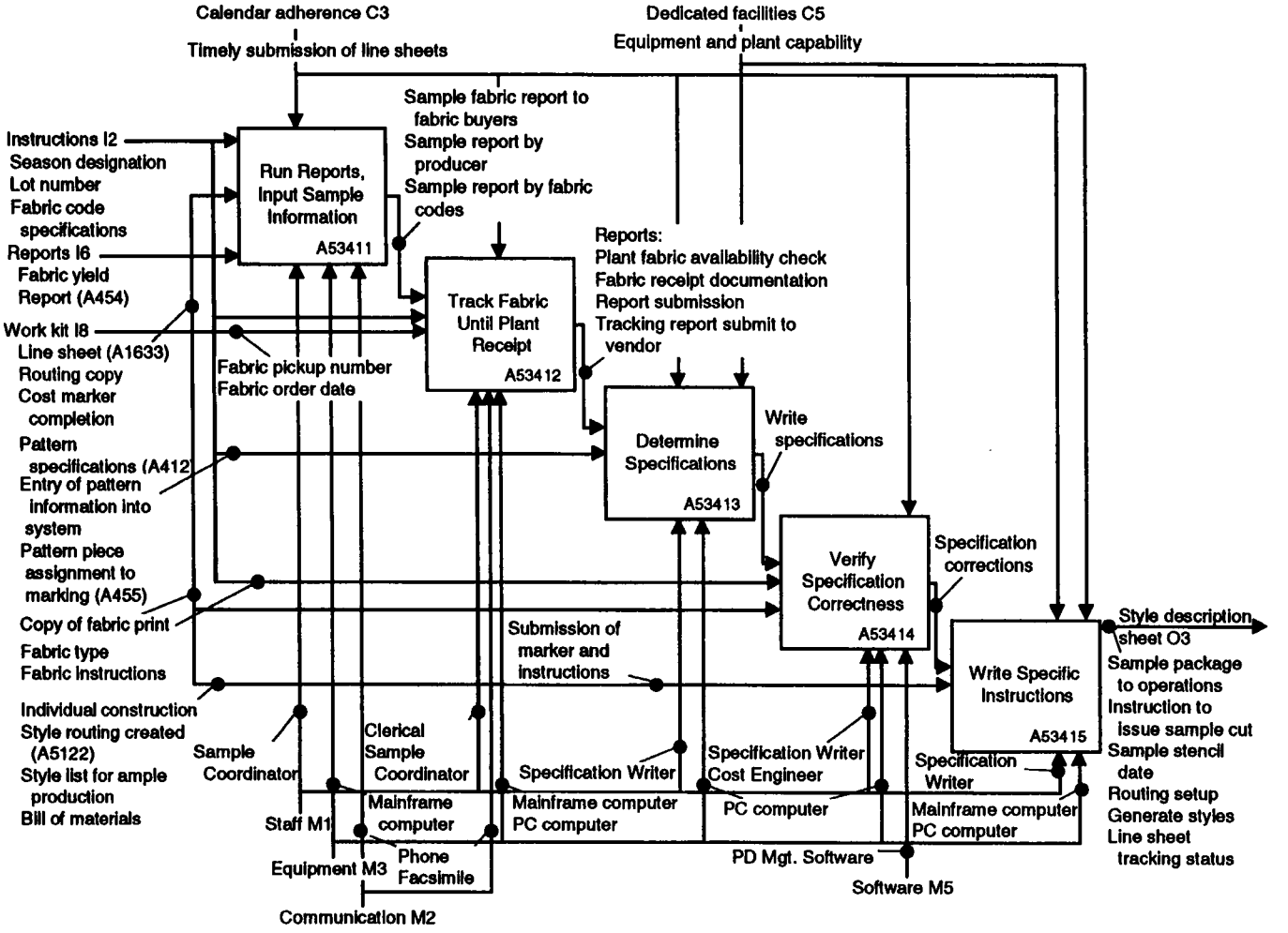
NODE: 533

Figure 102. Generate style development.



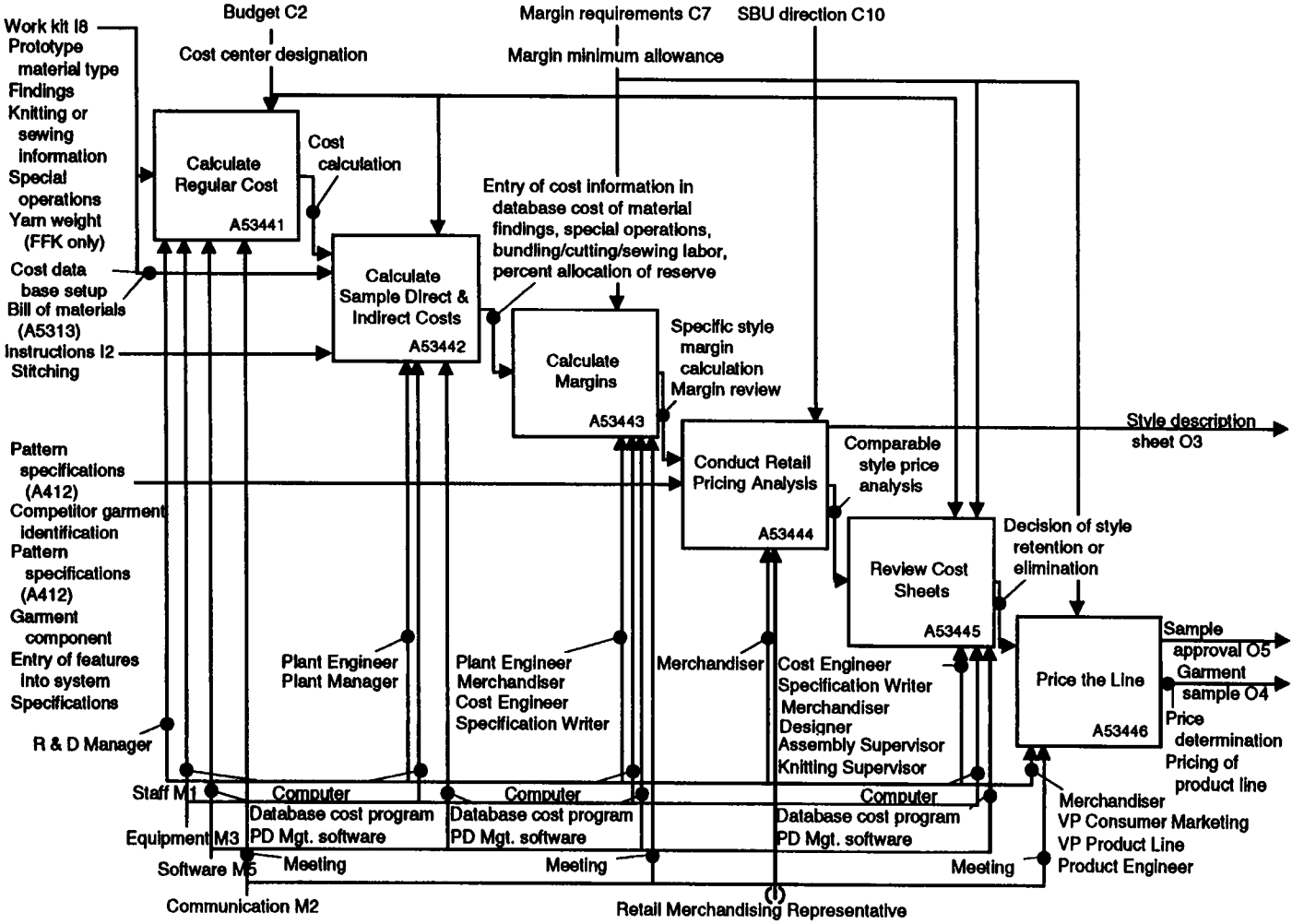
NODE: A534

Figure 103. Generate samples.



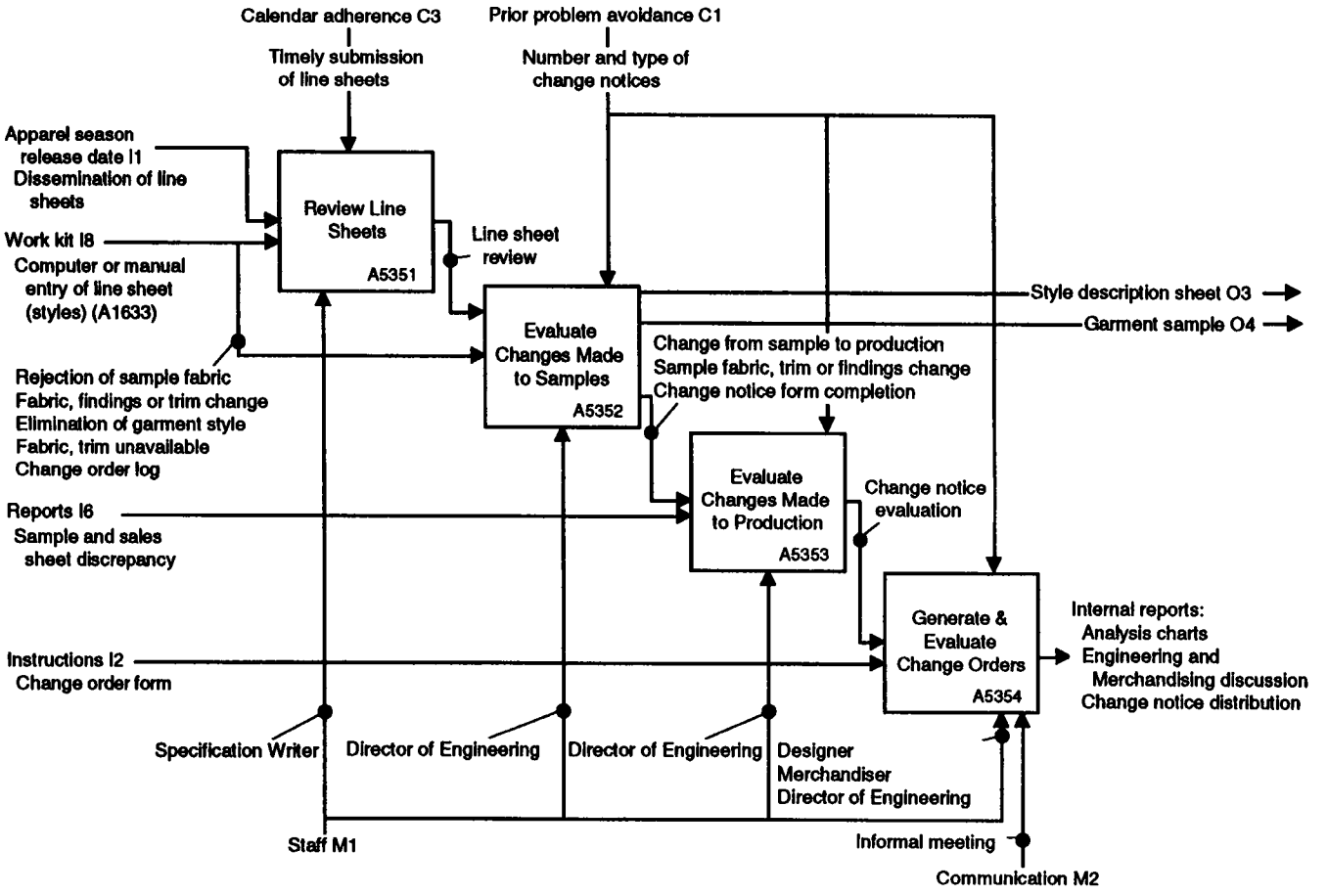
NODE: A5341

Figure 104. Create specifications and sample package.



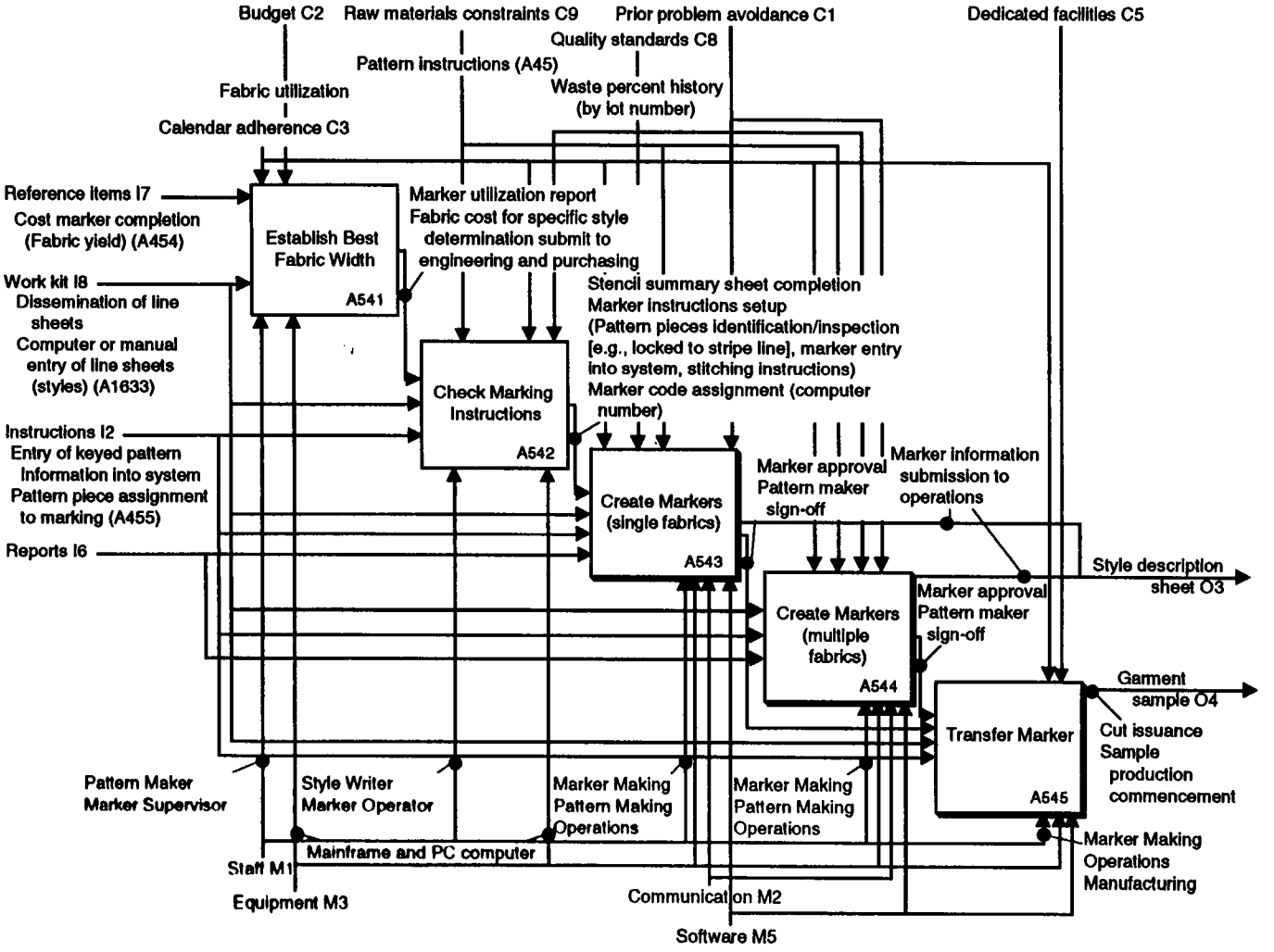
NODE: A5344

Figure 105. Conduct costing.



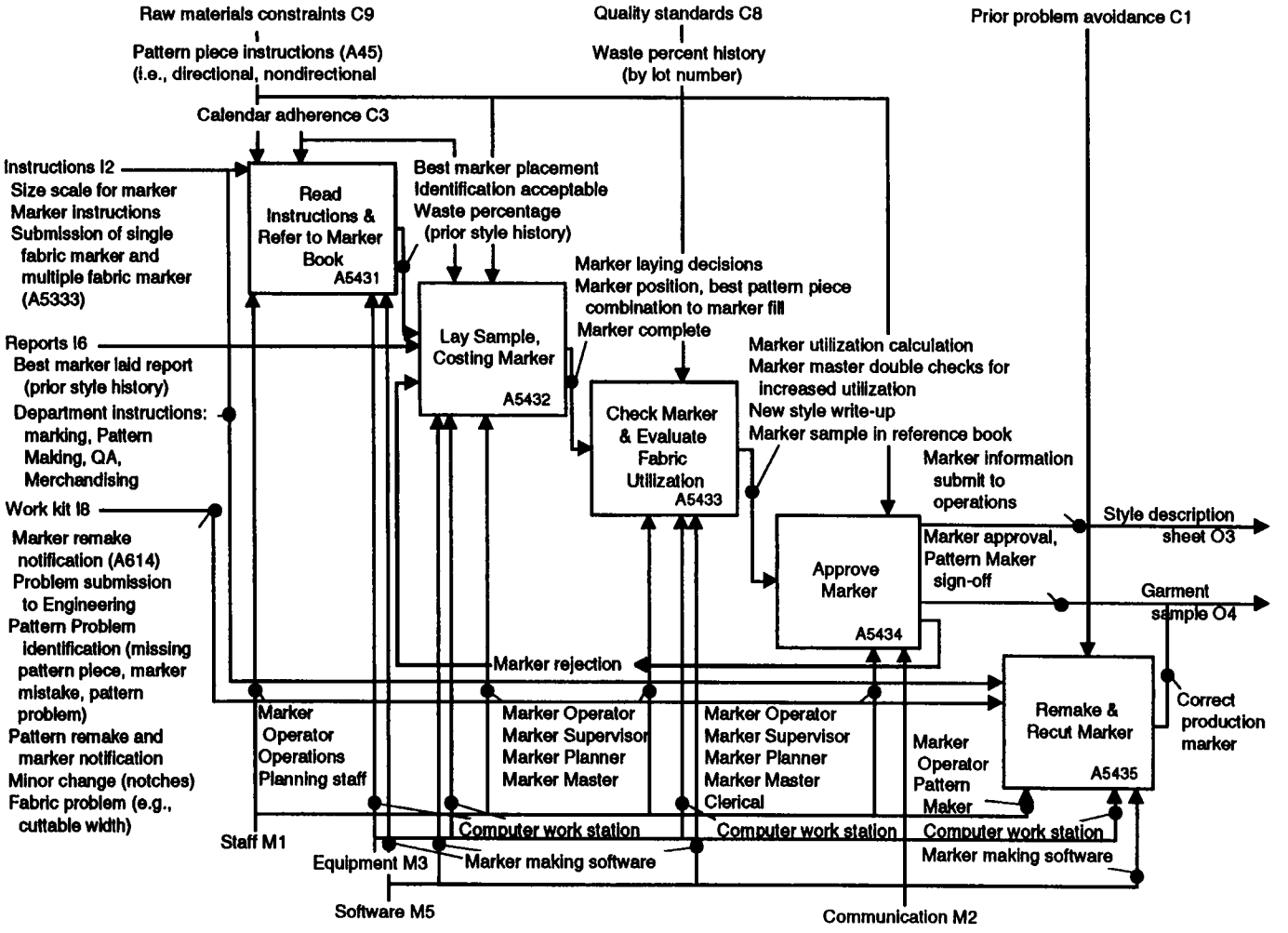
NODE: 535

Figure 106. Manage delay in production process.



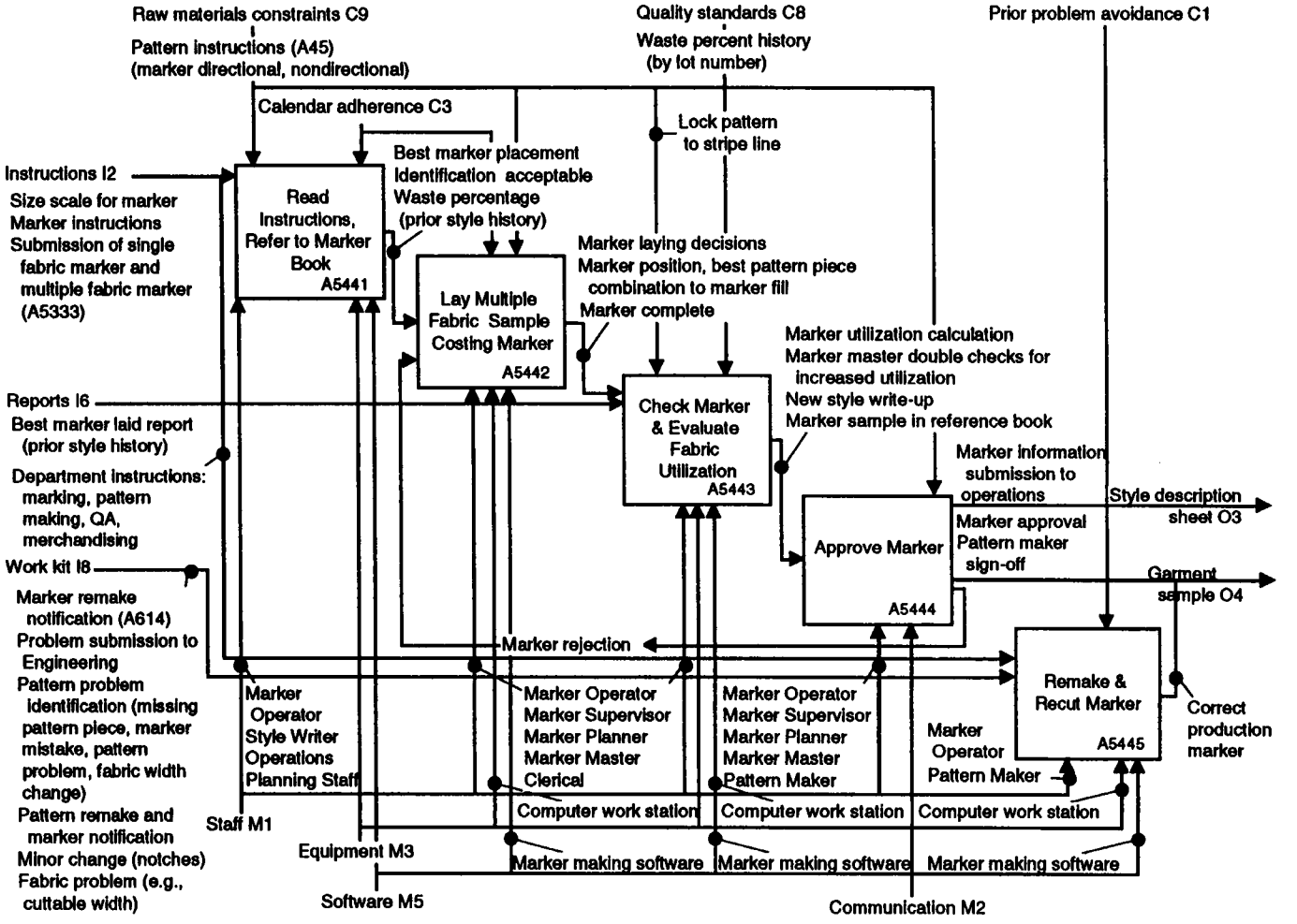
NODE: A54

Figure 107. Create markers.



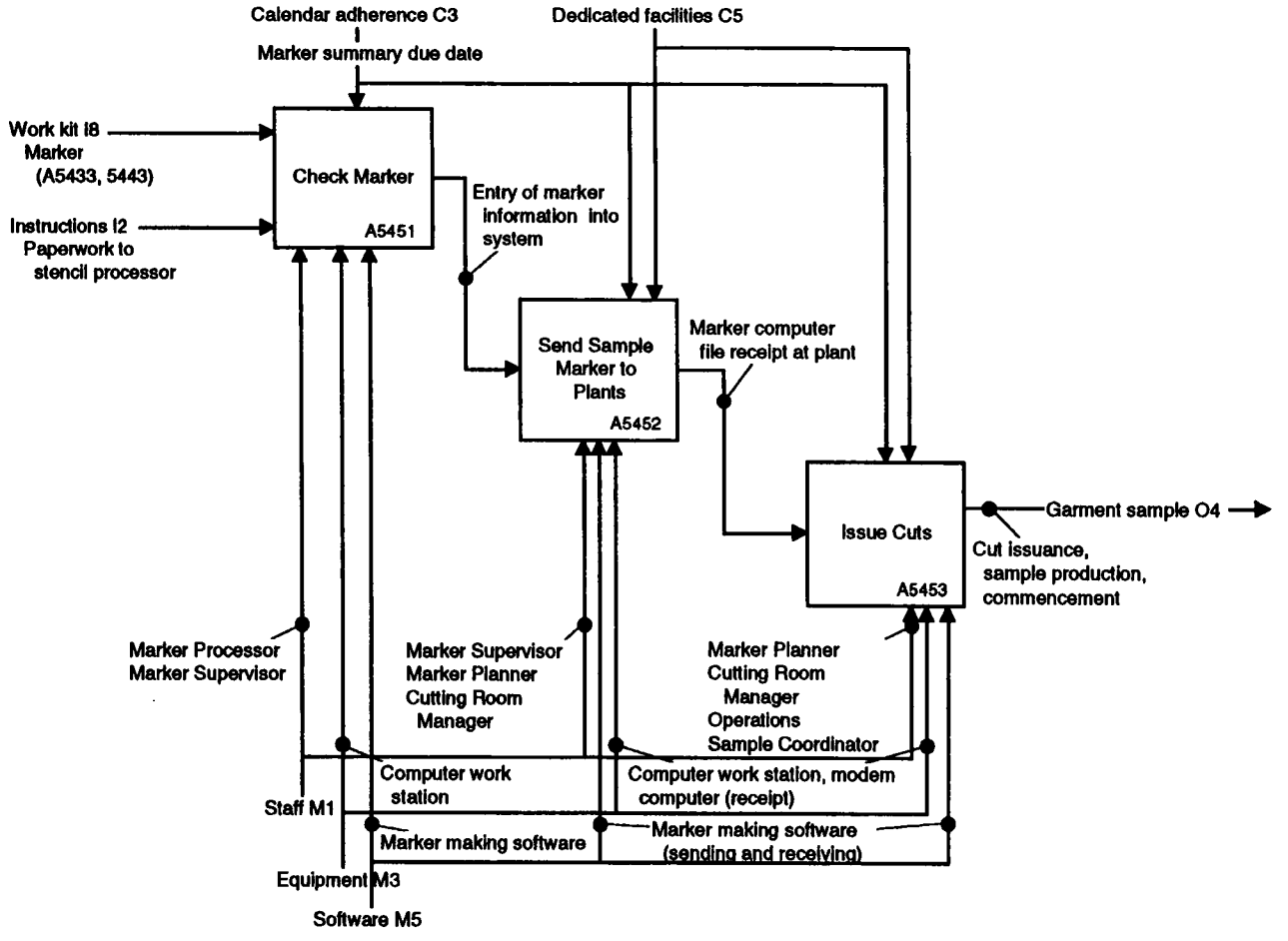
NODE: A543

Figure 108. Create markers (single fabrics).



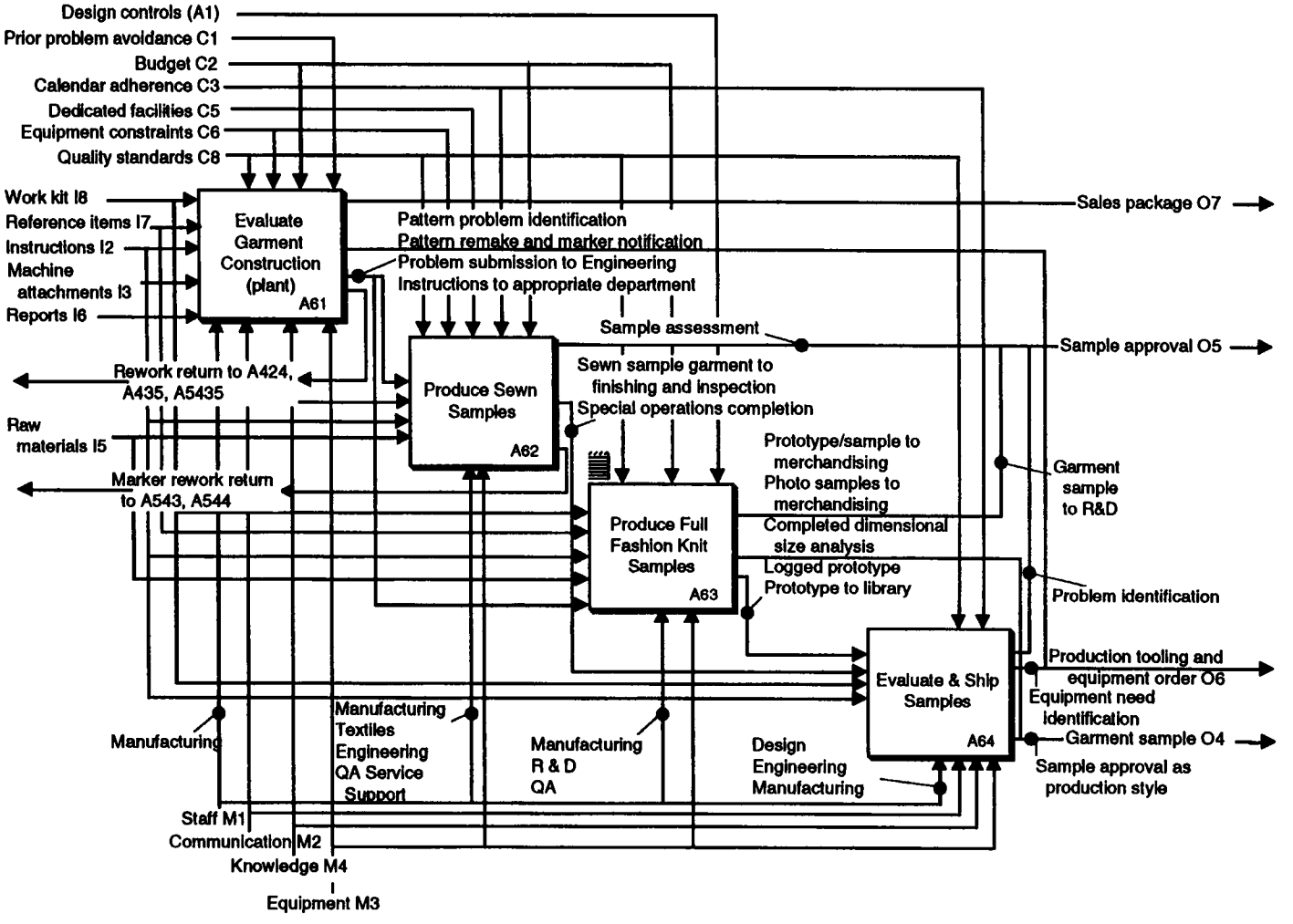
NODE: A544

Figure 109. Create markers (multiple fabrics).



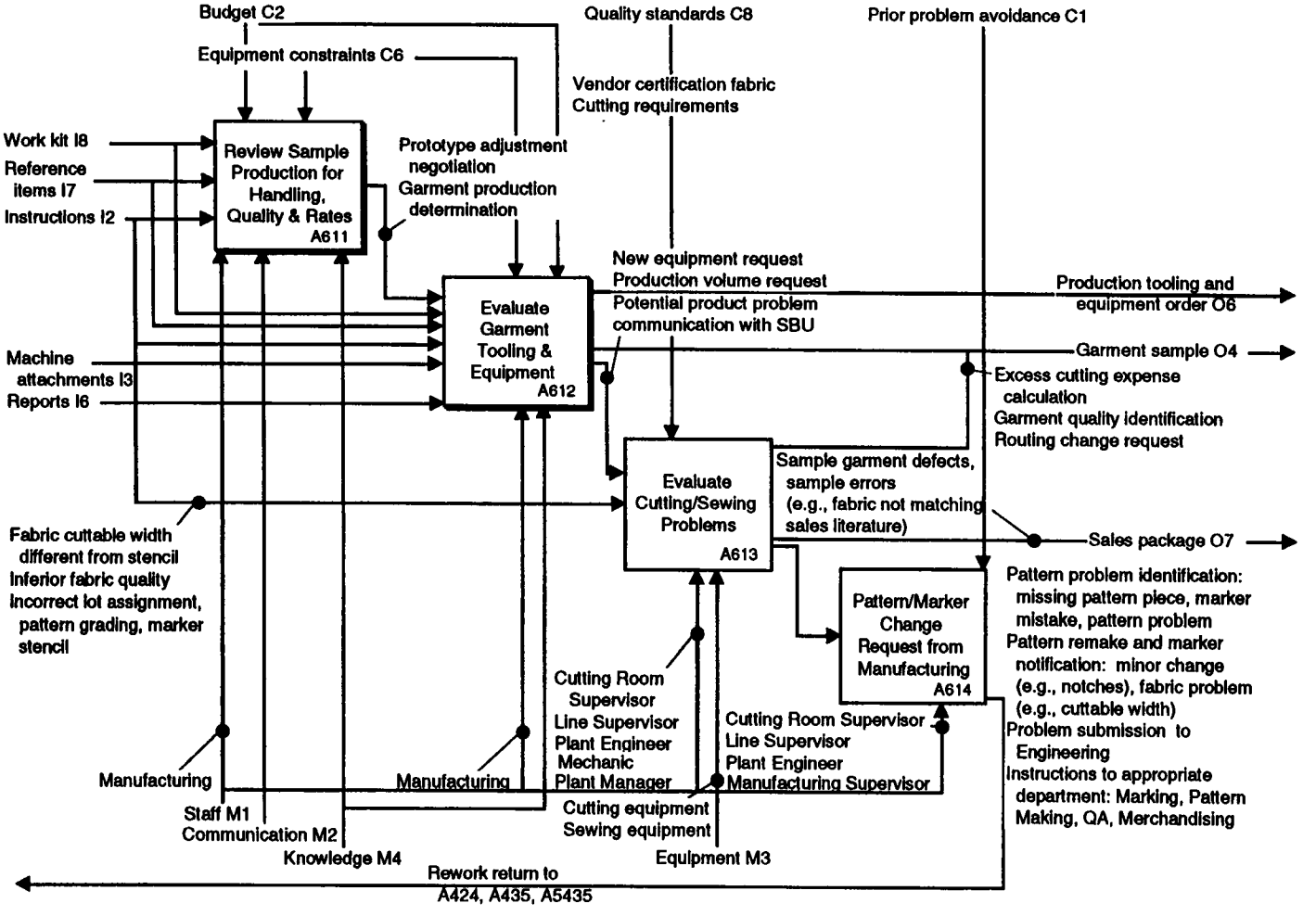
NODE: A545

Figure 110. Transfer marker.



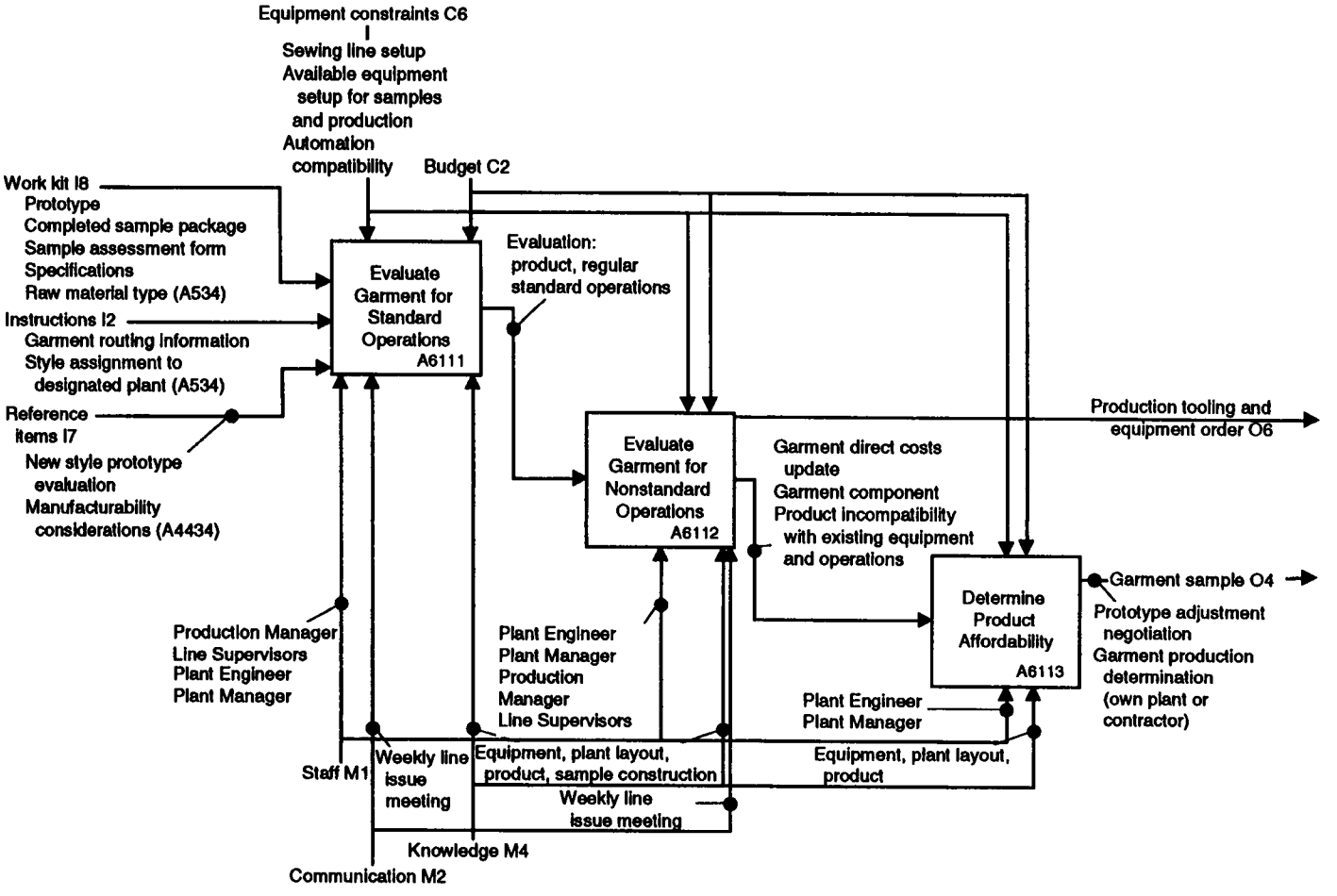
NODE: 6

Figure 111. Produce samples.



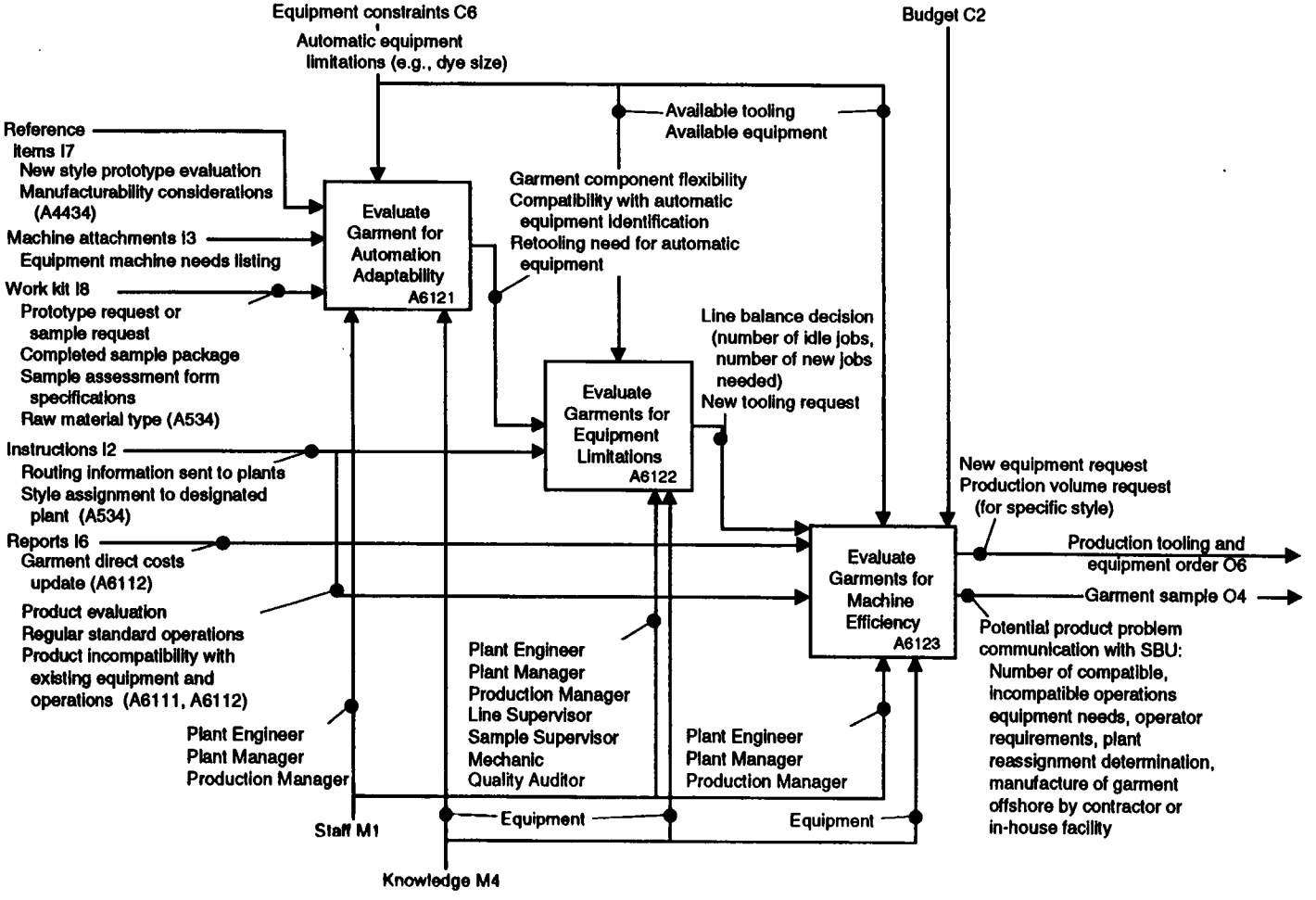
NODE: A61

Figure 112. Evaluate garment construction (plant).



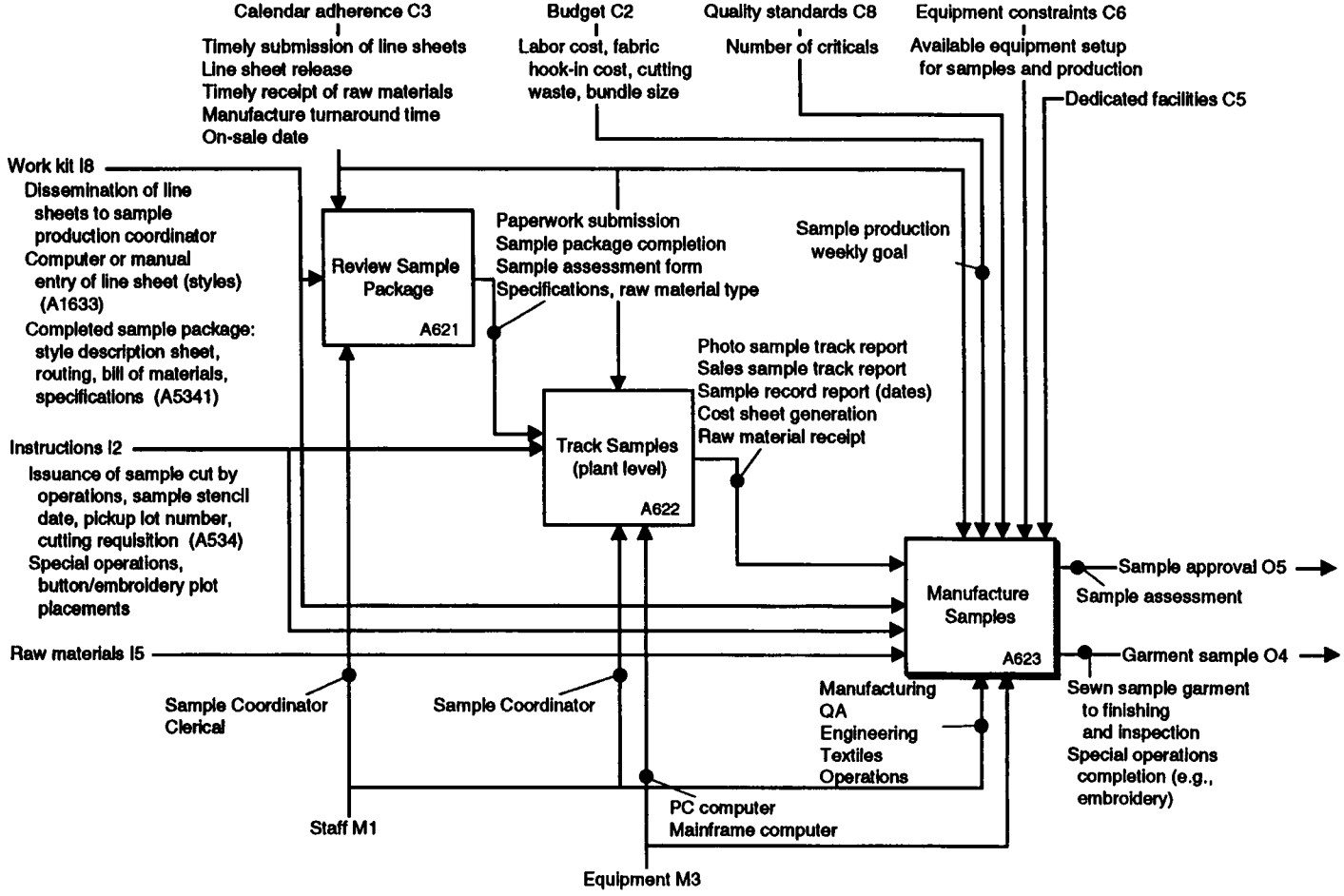
NODE: A611

Figure 113. Review sample production for handling, quality and rates.



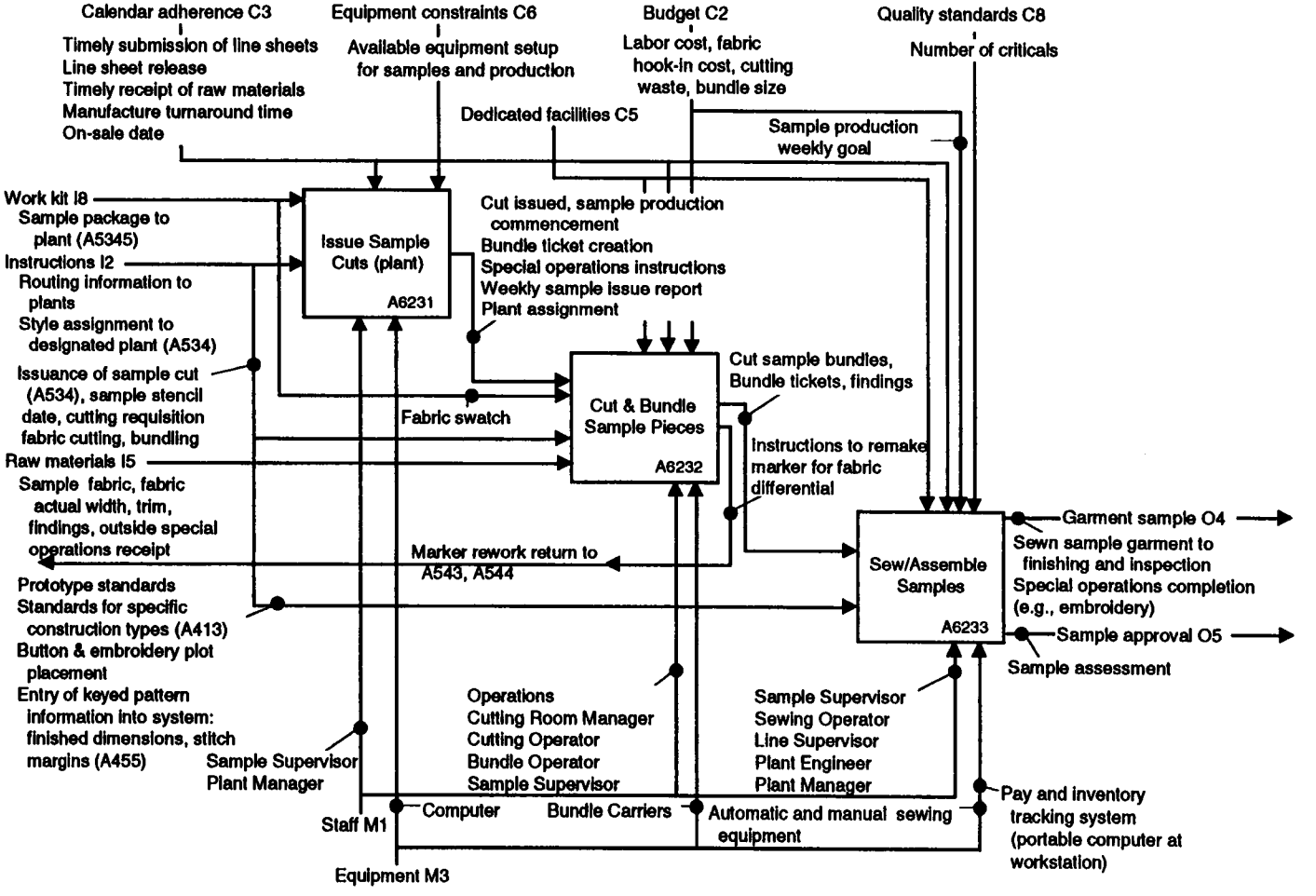
NODE: A612

Figure 114. Evaluate garment tooling and equipment.



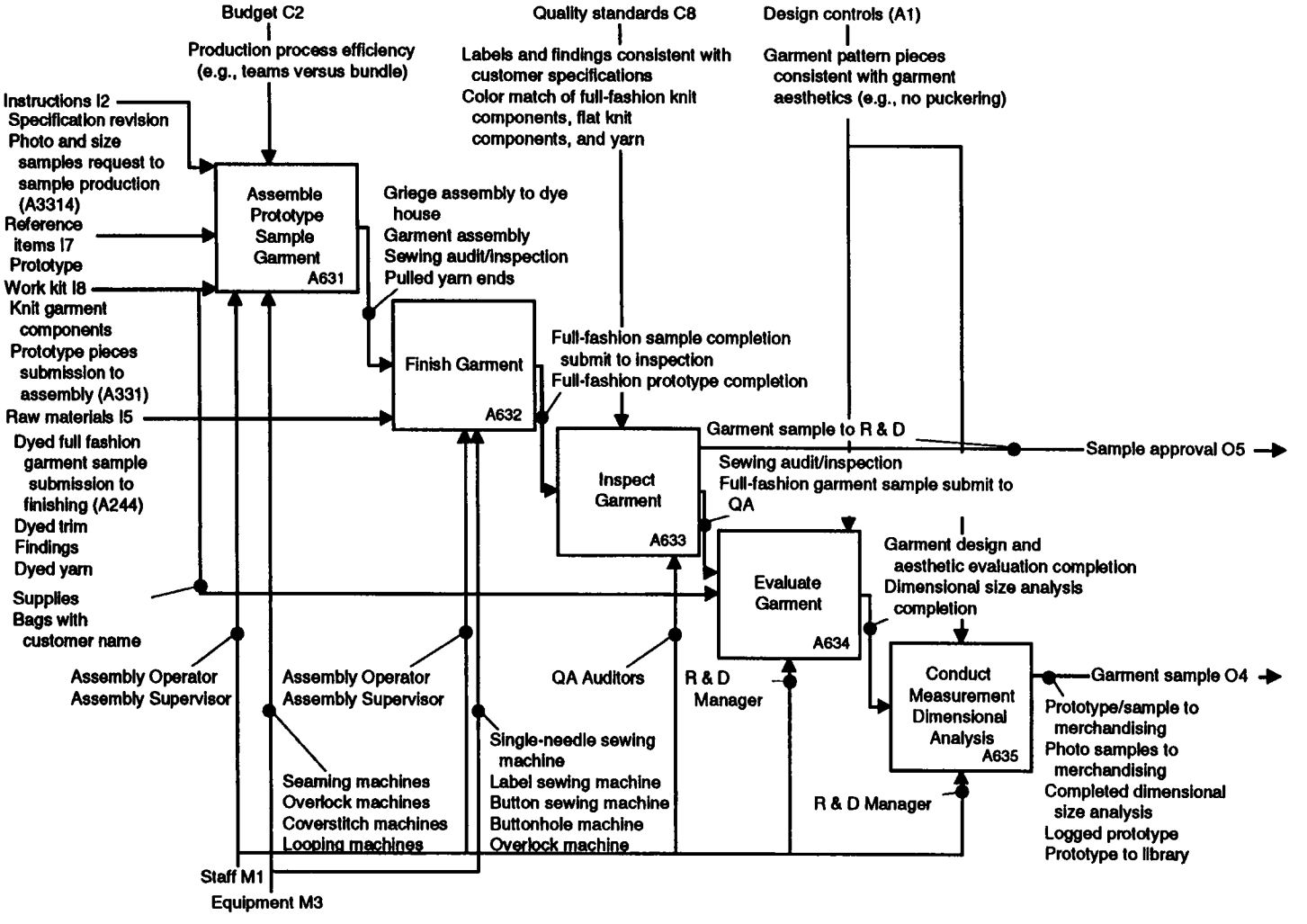
NODE: A62

Figure 115. Produce sewn samples.



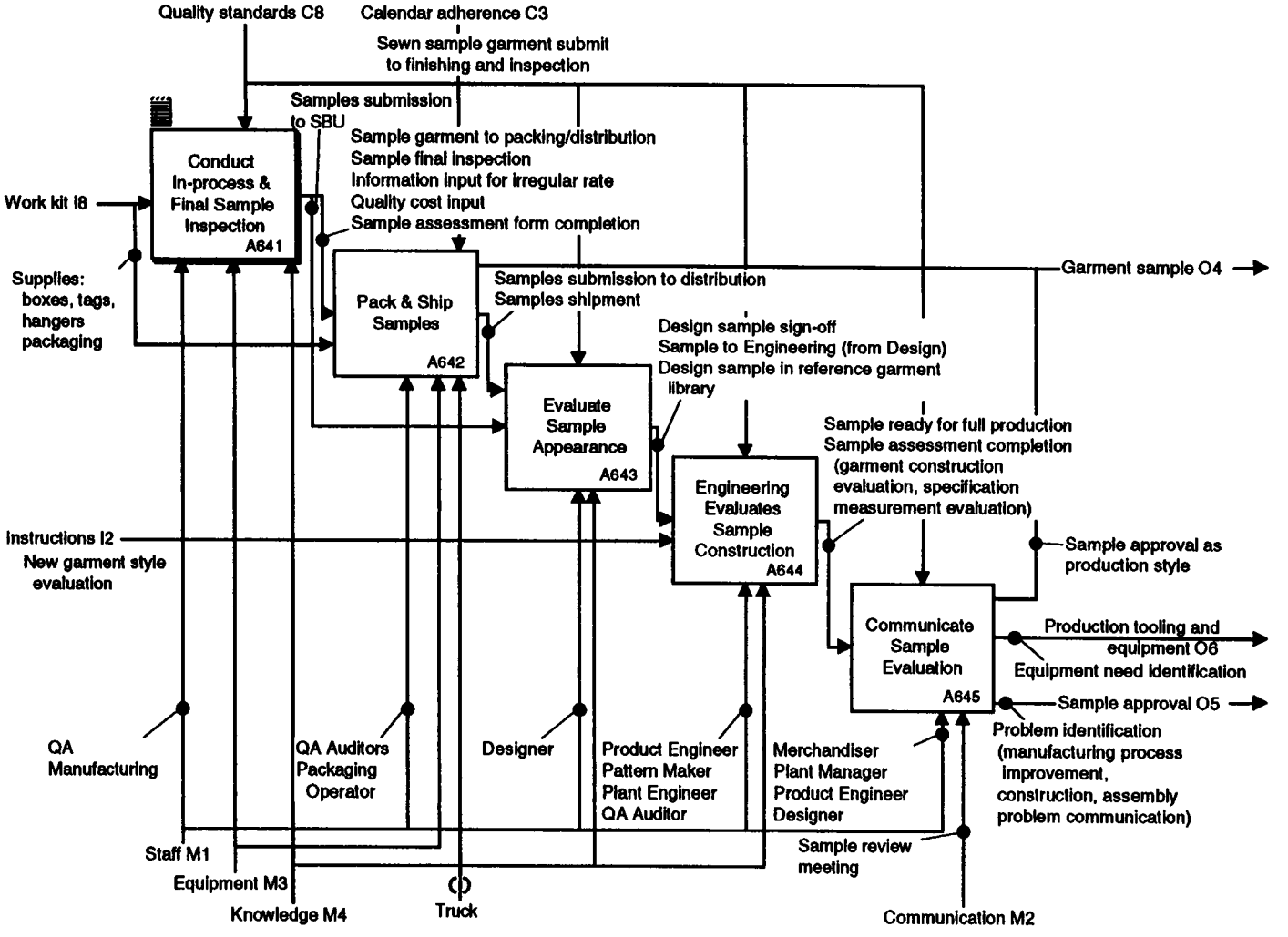
NODE: A623

Figure 116. Manufacture samples.



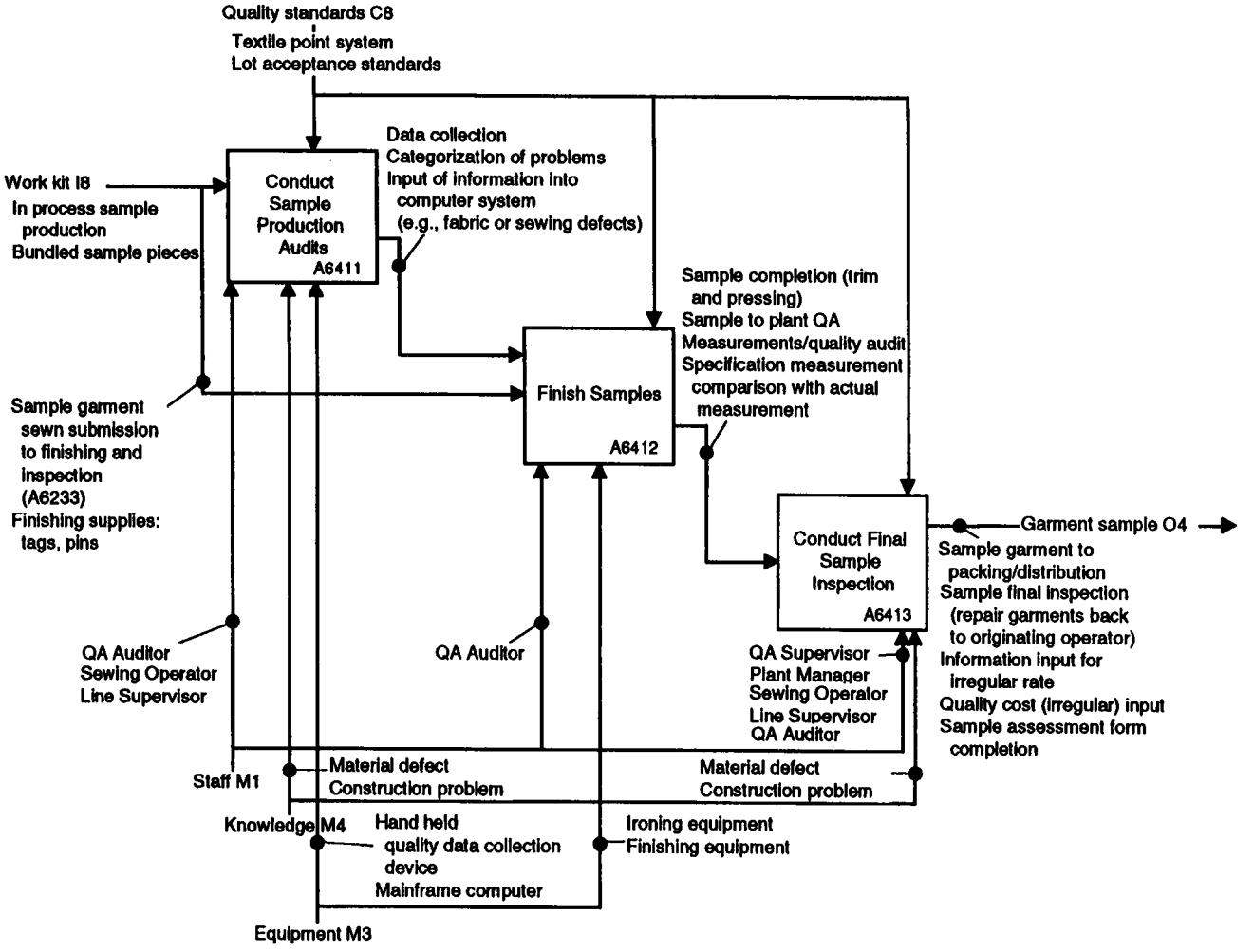
NODE: A63

Figure 117. Produce full fashion knit samples.



NODE: A64

Figure 118. Evaluate and ship samples.



NODE: A641

Figure 119. Conduct in-process and final sample inspection.

CHAPTER VI. RESULTS AND DISCUSSION: THE DEVELOPMENT OF A CE APPAREL FRAMEWORK FOR A *TO BE* ENVIRONMENT

Results and Discussion Overview

The purpose of the present study is to develop a CE framework specifically for apparel manufacture. Chapter VI consists of Phase Two results and discussion for the *to be* environment in which the researcher developed a CE framework to integrate the apparel design process with the product development process. Phase One results were the foundation for Phase Two. For Phase Two data collection the researcher gave questionnaires to apparel associate focus groups. Chapter VI $IDEF_0$ findings are the reorganization of apparel activities, the inclusion of multi-disciplinary design teams, and the use of enabling technology (i.e., mechanisms) for a *to be* environment. The reorganized apparel activities represent the primary processes from all functional areas in the *as is* environment. The *to be* environment results are presented in narrative and $IDEF_0$ analytic graphic diagrams. The *to be* environment $IDEF_0$ diagrams are organized by CE conceptual statements, CE operational statements, and apparel activities (see Figures 119 through 198). Each CE conceptual statement area (e.g., DFQ) shows the apparel associates' identification of apparel activities on the $IDEF_0$ diagrams. The $IDEF_0$ diagrams use the IDEF hierarchical structure to show the grouping of apparel activities into CE operational statements. Chapter VI results and discussion narrative explain how the *to be* apparel activity organization changed from the *as is* environment.

The researcher used Pawar and Driva's (1996) process capture conceptual framework as a guide for evaluating the *to be* environment for potential process performance improvement. Pawar and Driva indicated that identifying how change could be achieved is an important step in creating a CE environment. The projected process

performance improvements are based on questionnaire results from two focus groups of apparel associates. The apparel associates in the focus groups were asked to study the *to be* $IDEF_0$ posters while responding to a process performance questionnaire.

The apparel manufacturers in the study represented multiple merchandise classifications and were located in five states. Phase Two results are based on data collection from 34 apparel associates. The researcher used a focus group approach in which apparel associates completed written questionnaires. Phase Two data collection instruments were the design for manufacturability, quality, cost, and life cycle questionnaire; Q-Sort, multi-disciplinary team questionnaire; enabling technology questionnaire; and potential process performance improvement questionnaire (see Appendix D for data collection instruments).

The CE Approach to Create a *To Be* Environment

CE is not a sequential process as was shown in Phase One, the *as is* environment results. Rather, CE is the integrated concurrent design of products and their related processes (Winner et al., 1988). Turino's (1992) CE design process model illustrates the integrated concurrent design of products by showing that design activities are central while manufacturing, test, quality, and service activities (i.e., product development) support the design activities (see Figure 5). The narrative for each of the CE conceptual statement areas correspond with the $IDEF_0$ diagrams and depict how the apparel associates reorganized the *as is* apparel activities to integrate design with support activities in a *to be* environment.

In the CE approach, decisions are made as early as possible by using a concept called a design maturity curve. O'Brien and Smith (1994) defined design maturity as the time when a design is complete or mature enough to be released to downstream activities.

Ultimately, a design team's use of the design maturity curve shortens product development time by reducing rework. Using the design maturity concept lengthens an organization's design process so that a multi-disciplinary design team can concurrently address the design of products and their related processes issues within DFQ, DFET, DFM, DFLC-I, DFLC-R, DFLC-M, and DFC (Turino, 1992). Figure 120 shows the CE apparel design maturity curve.

Phase Two results narrative describes what apparel activity movement occurred within each CE conceptual statement area. The researcher evaluated the overall reorganization of the apparel activities to determine if the *to be* environment potentially could meet the CE conceptual statement area (e.g., DFQ) goals and the design maturity curve goals. The goals of the design maturity curve are for a design team to make changes and to address potential manufacturing problems early in the design process in order to reduce the number of design specification change orders. The ultimate goal is to have error-free assembly once the product goes into production (Menon, 1992b). The researcher's goal of the Q-sort instrument was to create a new design maturity curve. The results of the Q-sort are based on the apparel associates ranking of apparel activities into early (1), middle (2), and late (3) categories within each of the CE conceptual statement areas (e.g., DFQ). The apparel associates' ranking of apparel activities is illustrated in the lower left corner of each apparel activity box (see Figure 124 for an example). The researcher used *as is* environment product development time (i.e., 32 weeks) as a guide to evaluate the ranking of apparel activities and relate them to the design maturity curve. The activities identified as early (i.e., 1) could be completed during the first third of the product development cycle (i.e., approximately 0-10.7 weeks). Middle (i.e., 2) means that the apparel activities could be accomplished during the second third of the product development cycle (i.e., from approximately week 10.8 to week 21.4). The activities identified as late (i.e., 3) could be completed between week 21.5 and week 32, the last

third of product development time. If a rank was not provided by apparel associates, it is indicated by a # symbol.

The *To Be* Environment Conceptual Areas

The researcher used DFQ, DFET, DFM, DFLC-I, DFLC-R, DFLC-M, and DFC as CE conceptual statement areas in the CE apparel model. The CE conceptual statement areas drawn on the A-0 $IDEF_0$ hierarchical level diagram are based on the adapted CE framework models by Crow (1992) and Hyeon et al. (1993) (see Figure 10). The results of the CE design for manufacturability, quality, cost, and life cycle questionnaire were the foundation for the operational statements used in the CE apparel framework. Questionnaire results showed that the majority of the apparel associates in the focus groups had selected the use of CE operational statements all or some of the time. These results were used as the second $IDEF_0$ hierarchical level. The use of accepted operational statements in the CE apparel model is consistent with Carter and Stilwell-Baker's (1992) ideas that CE implementation needs a starting point. The CE conceptual statement areas are shown in Figure 121. The CE apparel operational statements used in the CE apparel framework are shown in Figures 122, 123, 142, 155, 167, 174, 189, and 194). For example, DFQ operational statements, selected by a majority of apparel associates, were design products for consumer requirements, select high quality components, benchmarking, design product to minimize manufacture variation, use specific values for design parameters, and maximize average part level (see Figure 122). The results of the questionnaire are detailed in Appendix A, published dissertation articles. The apparel activities, shown in each CE conceptual statement area $IDEF_0$ diagram, are the results of the Q-Sort. The apparel activities represent primary processes from the *as is* environment that apparel associates selected and validated to be a part of each CE conceptual statement area and CE operational statement area. The goals of the Q-sort were to break down

functional barriers and apparel paradigms of remaining in the mode of sequential apparel product development.

Design for Quality Apparel Activities

DFQ is defined as designing a product that conforms to customer requirements (Ehresman et al., 1991). The apparel associates selected DFQ apparel activities from four *as is* environment functional areas: create apparel line (A1), develop colors and prints (A2), create pattern and prototype (A4), and produce samples (A6). The apparel activities selected are consistent with the goal of quality function deployment (QFD) which is to create a conceptual map of customer attributes that can be translated into product engineering requirements (Carter and Stilwell-Baker, 1992). Apparel associates' selection of apparel line decisions, color development, and print creation apparel activities identifies customer attributes that are emphasized in QFD. The apparel line decision activities are those that represent business goals, consumers, themes, apparel line, colors, and apparel line merchandising (e.g., A11, A1134, A122, A161, A142) (see Figures 124, 125, 127, 128). Apparel associates selected color development and print creation apparel activities (e.g., A2322, A22124, A221) for designing printed fabrics, specifying color parameters, and developing dyes or pigments (see Figures 132, 133, 137). The QFD engineering requirements are met by the apparel associates' selection of apparel activities to evaluate previous seasons best sellers, sample appearance, sample construction, sample quality, and prototypes (e.g., A1353, A643, A644, A5211, A4433) (see Figures 130, 135, 138, 139).

DFQ apparel activities selected by the apparel associates that were ranked as early (1) were primarily from create design process (A1) (e.g., A11, A122), establish quality standards, develop knit and color specifications, and create pattern blocks (e.g., 413, A41, A3111) (see Figures 124, 125, 127, 128, 134, 141). The highest frequency of DFQ middle (2) activities are for color development, print development, prototype

development, and sample specification. For color development, apparel associates selected activities for color decisions, color recipe formulation, and color approval (e.g., A1421, A22126, A25) (see Figures 129, 133, 137). For color development and print development, the apparel associates selected apparel activities that specified fabric prints and textures, and evaluated fabric quality (e.g., A511, A3143, A31433) (see Figures 128, 129, 132). Middle (2) prototype activities selected were for the design, evaluation, and approval of prototypes (e.g., A1136, A444, A4435) (see Figures 125, 134, 139). Apparel associates selected DFQ apparel activities to conduct wear tests, to determine quality features, and to develop grade rules and sample specification activities (e.g., A5224, A52111, A451, A452) (see Figures 124, 138, 140. Late (3) DFQ activities selected by apparel associates were to evaluate customer and consumer feedback, and to evaluate cutting and sewing problems (e.g., A*[1], A613) (see Figures 124, 135).

Table 5 shows the dominant trend for the change of sequence in DFQ apparel activities from the *as is* environment to the *to be* environment. The shift in DFQ apparel activities in the *to be* environment supports the premise that design maturity lengthens the design process so that a multi-disciplinary design team can concurrently address the design of products and their related processes. The early apparel activities that shifted to middle activities are primarily design decisions and color evaluation. The late apparel activities that shifted to middle activities are process issues for either ordering fabric or assigning sample production (see Table 5).

[1] During data validation, apparel associates identified an A* activity as being outside the *as is* environment.

Table 5

An Overview of DFQ Apparel Activities Changes Between the *As Is* and *To Be* Environments

DFQ: Early *As Is* Apparel Activities that Shifted to Middle *To Be* Activities

Activity	Functional Activity Title
A1134	Observe consumers
A1136	Sketch reference items
A1353	Analyze competitor garments & sizes
A1421	Select colors
A1522	Evaluate & narrow colors
A15331	Create painting (manual or CAD)
A15333	Perfect coloration (manual or CAD)
A161	Decide optimum solution
A1641	Conduct concept meeting
A211	Send color standard to textile vendor
A221	Develop color for piece dye
A22126	Write color formulation
A2321	Review print package
A2322	Determine order to pitch & color position
A2333	Create color tabs
A24	Implement piece dye for garments
A25	Approve dyed color samples
A251	Compare color submit to color standard

DFQ: Late *As Is* Apparel Activities that Shifted to Middle *To Be* Activities

Activity	Functional Activity Title
A511	Evaluate & specify fabrics
A5224	Conduct & evaluate wear tests & garment tests
A53414	Verify specification correctness
A5343	Implement specification change
A5354	Generate & evaluate change orders
A643	Evaluate sample appearance
A644	Engineering evaluates sample construction

Design for Enabling Technology Apparel Activities

DFET is defined as the concurrent sharing of information in a seamless, cooperative environment (Prasad, 1996). The apparel associates selected DFET apparel

activities from the three *as is* environment areas of create apparel line (A1), develop colors and prints (A2), and set production specifications (A5) (see Figures 145, 147 for examples). A DFET goal is to share knowledge (Carver & Bloom, 1991). Specific apparel activities which exemplify sharing knowledge were selected by apparel associates. The specific apparel activities are determining minimum plans, developing category plans, conducting line reviews, understanding market concept, and determining apparel assortments (e.g., A111, A16342, A112) (see Figures 144, 152). In the *as is* environment, the information from these activities is communicated through meetings or computers. Apparel associates selected some computerized routine activities from the *as is* environment to represent DFET. Apparel associates described routine computerized activities such as assigning fabric codes for internal reports. Some of the *to be* environment routine computerized activities selected for DFET were activities for generating reports for tracking samples, assigning numbers for fabrics and garments, and writing specifications, (e.g., A5345, A5321, A5114, A 33114) (see Figures 145, 147, 148).

Apparel associates selected early (1) DFET activities for planning business activities and for searching for design alternatives. Some specific DFET business activities selected by apparel associates were to conduct sales forecast and line review, determine category plan, and conduct classification analysis (e.g., A1643, A16342, A1352) (see Figures 144, 154). Some early (1) selections representing searching for design alternatives were to sketch designs, observe consumers, and to use fabric and silhouette libraries (A1354, A1134, A1351) (see Figures 151, 152, 153). The apparel associates selected middle (2) DFET activities for finalizing colors, determining knit specifications, setting up fabric technical requirements, and designing carry-over garments (e.g., A152, A33114, A534, A2323, A155) (see Figures 147, 148, 153, 151). Late (3) DFET activities selected by apparel associates were to develop sales sheets,

review reports, and to transfer markers (e.g., A1634, A513, A545) (see Figures 144, 145, 149).

Table 6 shows the dominant trend for the change in sequence in DFET apparel activities from the *as is* environment to the *to be* environment. Using the product development calendar as a guide, design activities such as understanding marketing concept, buying reference items, and observing consumers are accomplished within the first two weeks of the *as is* environment (i.e., early design maturity). In the *to be* environment, these activities were moved to middle activities, later in the process (approximately week 10.8 to week 21.4). The later placement of these activities implies that the activities could be completed at a later design maturity stage when the design team has more information. The late activities that shifted to middle activities are primarily from conduct purchasing (A51) and conduct engineering process (A53). The movement of the apparel activities implies that purchasing and engineering should have earlier involvement in the process. Activities such as review line sheets and garment tracking (i.e., samples, fabrics, lots) could be conducted earlier in the *to be* environment.

Table 6

An Overview of DFET Apparel Activities Changes Between the *As Is* and *To Be* Environments

DFET: Early *As Is* Apparel Activities that Shifted to Middle *To Be* Activities	
Activity	Functional Activity Title
A 1643	Conduct line review & sales forecast
A112	Understand marketing concept
A1133	Buy reference items
A1134	Observe consumers
A1136	Sketch reference items
A152	Finalize color palette
A155	Design carry-over garments (bodies)
A1615	Project fabric & trim quantities
A1632	Enter line sheets into database
A1634	Develop sales sheets
A16342	Determine category plan
A213	Compile color library
A22126	Write color formulation
A23124	Send package to engraver
A2323	Determine pattern step & repeat

DFET: Late *As Is* Apparel Activities that Shifted to Middle *To Be* Activities	
Activity	Functional Activity Title
A5111	Identify piece goods
A5114	Assign fabric codes
A5321	Assign style/lot number
A5331	Review line sheets
A5341	Create specifications & sample package
A53412	Track fabric until plant receipt
A5345	Track samples & special operations
A6121	Evaluate garment for automation adaptability

Design for Manufacturability Apparel Activities

DFM is defined as designing producibility into a product rather than modifying a design to correct deficiencies prior to manufacture release (Crow, 1992). The apparel associates selected DFM activities from four functional areas within the *as is* environment:

implement fabric design and special operations (A3), create pattern and prototype (A4), set production specifications (A5), and produce samples (A6) (see Figures 157, 158, 159 for examples). Apparel associates selected apparel activities that meet the overall DFM goal. Boothroyd (1992) stated the overriding goal of DFM is to evaluate and improve a design for manufacturability and assembly during the design process. Specific apparel activities to evaluate a design are represented in apparel activities for evaluating garments for equipment efficiency, automation, tooling needs, and limitations (e.g., A6123, A6121, A612, A6122) (see Figure 157). Apparel activities that apparel associates selected for improving a design are represented by determining specifications, observing the manufacturing process, training quality supervisors, and evaluating fabric and garment sewability (e.g., A53413, A*, A*, A5223) (see Figures 160, 162, 163, 164). Apparel associates selected apparel activities that addressed assembly issues for creating patterns and prototypes. The apparel activities for assembly include providing essentials to prototyping, requesting piece goods tests and test cuts, determining specifications, producing samples, and creating markers (e.g., A441, A5311, A53413, A62, A544) (see Figures 158, 159, 160, 161, 165). Apparel associates also selected problem solution activities to represent DFM. Specific problem solution apparel activities include evaluating cutting and sewing problems, and managing delays in production (e.g., A613, A535) (see Figures 163, 164).

The apparel associates selected early (1) DFM apparel activities to evaluate a garment for machines and for sewability. The specific early (1) activities representing evaluate garment for machines include efficiency evaluation and automation adaptability (e.g., A6123, A6121) (see Figure 157). Specific early (1) activities for evaluating garment sewability are to assemble prototypes, evaluate sewability of raw materials and garments (e.g., A631, A5223, A5314) (see Figures 158, 164). Middle (2) DFM activities are those that apparel associates selected to create patterns and prototypes, evaluate raw

materials, and evaluate garments. The apparel associates selected create pattern activities for developing first patterns, assembling knit prototypes, and submitting pattern instructions (e.g., A423, A631, A455) (see Figures 158, 159). Apparel associates selected DFM apparel activities for evaluating raw materials, requesting piece good tests, and evaluating new fabrics and trims for sewability (e.g., 5311, A5314) (see Figures 159, 164). The apparel associates selected garment evaluation as middle (2) activities to evaluate garments for nonstandard operations, limitations, and affordability (e.g., A6112, A6122, A6113) (see Figures 157, 159). Late (3) DFM activities selected by apparel associates are to make changes and to evaluate garments. Apparel activities representing making changes include request pattern changes or marker changes (e.g., A614) (see Figure 161). Evaluating garment apparel activities include the evaluation of sample garment appearance, garment construction, and cost markers for efficiency (e.g., A643, A644, A5442) (see Figures 161, 165).

The dominant trend for the change in apparel activity movement is that many DFM activities are moved to an earlier stage in the *to be* environment (see Table 7). The movement of activities supports the CE guidelines that the ideal time for product change is during design and product development, rather than approaching or during production (Menon, 1992a). The movement of activities from late to the early or middle stages is in concert with the DFM definition which is to design producibility into a garment and to correct deficiencies prior to manufacture release (Crow, 1992). Evaluating garments for sewability, efficiency, and automation adaptability are examples of apparel activities which are used to design producibility into a garment. Training quality supervisors, evaluating equipment limitations, and evaluating new tooling needs are ways that apparel associates can correct deficiencies prior to manufacture release. The apparel associates indicated that work-in-process errors created excess cost in the *as is* environment. The movement of DFM apparel activities to earlier stages in product development could help

reduce excess cost from work-in-process errors found during the *as is* environment's sample production (A6).

Table 7

An Overview of DFM Apparel Activities Changes Between the *As Is* and *To Be* Environments

DFM: Late *As Is* Apparel Activities that Shifted to Early *To Be* Activities	
Activity	Functional Activity Title
A5223	Evaluate garment sewability
A5314	Evaluate sewability of fabric & trim
A6121	Evaluate garments for automation adaptability
A6123	Evaluate garments for machine efficiency
A631	Assemble prototype sample garment

DFM: Late *As Is* Apparel Activities that Shifted to Middle *To Be* Activities	
Activity	Functional Activity Title
A*	Observe manufacturing process
A*	Train quality supervisors on manufacturing process
A*	Improve manufacturing quality
A5111	Identify piece goods
A5112	Identify trims & findings
A5123	Generate sample purchase order
A5133	Relay fabric reports
A5311	Request new fabric, trim, or sewing application
A532	Assign sample production
A5341	Create specifications & sample package
A5342	Determine & write routing
A535	Manage delay in production process
A6112	Evaluate garment for nonstandard operations
A6113	Determine product affordability
A612	Evaluate garments for new tooling purchase or need
A6122	Evaluate garments for equipment limitations
A62	Produce sewn samples
A622	Track samples (plant level)

Design for Life Cycle-Inspectability Apparel Activities

DFLC-I is the ability for a multi-disciplinary team to make choices that will minimize product development cost by having needed equipment to test or inspect a product at various production stages (Crow, 1992). The apparel associates selected DFLC-I activities primarily from two functional areas within the *as is* environment: develop colors and prints (A2) and set production specifications (A5). The DFLC-I apparel activities are those that apparel associates defined as quality assurance (QA) activities in the *as is* environment. In the *to be* environment, QA apparel activities are activities designed for color approval, griege good inspection, sample garment inspection, and garment sewability evaluation (e.g., A251, A5212, A641, A5223) (see Figures 169, 170, 172, 173). The specific DFLC-I apparel activities selected for color approval are color submission and comparing color standards (e.g., A211, A251) (see Figure 169). For raw material inspection, garment inspection, and garment sewability evaluation, the apparel activities selected by apparel associates show decisions that are made for piece good quality, griege good inspection, in-process and final garment inspection, and garment sewability evaluation (e.g., A224, A5212, A3143, A641, A5223) (see Figures 169, 170, 172, 173).

The ability for a design team to make design choices that minimize product development cost was reflected by a potential to reduce replicated color process activities. No DFLC-I activities were selected as early (1) activities. For middle (2) DFLC-I activities, apparel associates selected QA activities that involve color development, testing raw materials, and setting procedures for fabric acceptance. Specific color development apparel activities selected were to submit color standards and evaluate colors (e.g., A211, A251) (see Figure 169). Apparel associates selected DFLC-I middle (2) activities on evaluating raw materials for piece goods tests, trims, and yarns (A224, A5212, A5312, A5214, A5216) (see Figures 169, 170, 171). Setting procedures for substandard fabric

(A52113) supports the DFLC-I operational statement for a design team to specify product parameters (see Figure 171). Garment quality testing and inspection were chosen as late (3) DFLC-I apparel activities (e.g., A A3452, A5212) (see Figures 168, 172).

Table 8 shows the dominant trend for the change in sequence in apparel activities from the *as is* environment to the *to be* environment. Early (1) color activities in the *as is* environment shifted to middle *to be* activities. The shifting of color activities from early to middle is consistent with the trend in DFQ (see Table 5). Color development in the *as is* environment has a high volume of rework (i.e., 3-10 times per color), creating high replications of the color development cycle (e.g., generate color pigment replicated 400-700 times per season). The movement of color activities from early to middle implies that color decisions could be made later during product development and has the potential for reducing the high number of replications in color development activities. A reduction of color development replications could reduce excess costs. The late *as is* apparel activities that have shifted to an earlier stage involve testing and inspecting raw materials and garments at an earlier stage. The shift in these apparel activities is in concert with a DFLC-I operational statement which is to have early involvement of QA.

Table 8

An Overview of DFLC-I Apparel Activities Changes Between the *As Is* and *To Be* Environments

DFLC-I: Early *As Is* Apparel Activities that Shifted to Middle *To Be* Activities

Activity	Functional Activity Title
A211	Send color standard to textile vendor
A2211	Log standard, send to colorist
A224	Evaluate piece good quality
A251	Compare color submit to color standard

(table continues)

DFLC-I: Late *As Is* Apparel Activities that Shifted to Middle *To Be* Activities

Activity	Functional Activity Title
A52113	Set procedure for substandard fabric acceptance
A5213	Control & inspect griege goods
A5214	Test textile piece goods
A5215	Evaluate fabric problem
A5216	Test yarn weight (FFK)
A5223	Evaluate garment sewability
A5312	Submit piece good test
A5313	Sew trim & piece goods or test cut

Design for Life Cycle-Reliability Apparel Activities

DFLC-R is defined as evaluating a product's ability to remain functional for a specified period of time when used for its designated purpose (Blanchard et al., 1995). The apparel associates selected DFLC-R activities primarily from five functional areas within the *as is* environment: create apparel line (A1), develop colors and prints (A2), implement fabric design and special operations (A3), create garment pattern and prototype (A4), and set production specifications (A5). DFLC-R apparel activities have the highest representation for multiple *as is* functional areas.

From the activities selected, the apparel associates interpreted the definition of DFLC-R as the ability of a product to remain functional with apparel activities to create patterns and prototypes, design colors and fabrics, and to develop colors and fabrics. The apparel associates selected nine pattern and prototype apparel activities (e.g., A41, A4223, A451) (see Figures 178, 179, 181). The apparel associates selected seven color and fabric design activities (e.g., A511, A152) (see Figures 180, 184), and 16 color and fabric development activities (e.g., A332, A22126, A22124, A3114) (see Figures 183, 184, 185, 185). Color development activities selected include the editing and modifying colors, finalizing color palette, developing colors, and approving colors (e.g., A3123,

A152, A22124, A22125) (see Figures 180, 184, 185). Fabric print activities are primarily for specifying fabrics, participating in fabric meetings, editing prints, and conducting fabric engraving activities (e.g., A511, A1341, A3113, A311) (see Figures 180, 183, 184, 187).

The DFLC-R apparel activities selected by apparel associates as being early (1) are to use design or company goals in designs and to make fabric decisions. Apparel activities for company goals are using company mission and business goals in designs, using vendor certification, and determining core and reorderable strategy (e.g., A1121, A11, A5216, A131) (see Figures 176, 183, 188). Use of vendor-partner relationships, a DFLC-R operational statement, was supported by the apparel associates' selection of participation in textile concept meetings with textile vendors (A1341) (see Figure 183).

Some of the middle (2) DFLC-R apparel activities selected by apparel associates support the DFLC-R goal to eliminate defects and early failures prior to shipping. Some examples of DFLC-R apparel activities selected by apparel associates that support this goal are to proof patterns, develop patterns, modify designs for fabric printing, adopt vendor certification, create and approve color tabs, develop prototypes, and print leader cloth (e.g., A4233, A1524, A5216, A2333, A2334, A22126, A31422) (see Figures 179, 180, 183, 184, 185, 188). Late (3) DFLC-R apparel activities selected by apparel associates support the DFLC-R operational statement of perfecting a prototype through design and test iterations. Some apparel activities that support this operational statement are to evaluate prototypes for aesthetics and for manufacturability issues (A4432, A4434) (see Figure 179).

Table 9 shows the dominant trend for change in the DFLC-R sequence in apparel activities from the *as is* environment to the *to be* environment. Table 9 shows that design, develop color, and develop print apparel activities from the *as is* environment moved to the middle *to be* activity stage. The trend is consistent with the design and color apparel

activity movement that occurred in DFQ and DFLC-I (see Tables 5, 8). Some *to be* environment fabric engraving activities in DFLC-R remained consistent with their relative position in the *as is* environment. For example, create technique effects and engrave screens are middle activities in the *to be* environment and are middle activities in the *as is* environment (e.g., A3114, A312). Combining the movement of activities with the activities that remained stationary could be interpreted as apparel associates making decisions and conducting processes in parallel. An example of this is apparel associates making decisions on finalizing colors (i.e., A152) with engraving screens, which is a production process (i.e., A312) (see Figures 184, 187).

Table 9

An Overview of DFLC-R Apparel Activities Changes Between the *As Is* and *To Be* Environments

DFLC-R: Early *As Is* Apparel Activities that Shifted to Middle *To Be* Activities	
Activity	Functional Activity Title
A113	Search environment for information
A152	Finalize color palette
A1524	Get print colors in correct & consistent coloration
A153	Finalize fabric prints & textures
A1563	Evaluate garment bodies
A1631	Complete line sheet
A22124	Match lab dip to color standard
A22125	Approve color
A22126	Write color formulation
A2322	Determine order to pitch & color position
A2333	Create color tabs
A2334	Approve color tabs

Design for Life Cycle-Maintainability Apparel Activities

DFLC-M is the consideration of the actions necessary to retain or restore a product to a desired condition (Blanchard et al., 1995). DFLC-M apparel activities are from three *as is* environment functional areas: implement fabric design and special operations (A3), create garment pattern and prototype (A4), and set production specifications (A5). The findings show that DFLC-M had the least number of apparel activities. During data validation, the apparel associates indicated to the researcher that they had difficulty understanding the maintainability concept. Merkel (1991) indicated that apparel and textile manufacturers evaluate maintainability through garment tests, wear tests, and fabric performance tests. Merkel's definition is supported by the apparel associates' selection of the apparel activity test textile piece goods (A5214) (see Figure 191). In the *as is* environment, some apparel associates defined carry-over and reorderable garments as designs previously made by the apparel manufacturer. Apparel associates selected creating carry-over garments and determining strategy for reorderable or core items as part of DFLC-M (i.e., A43, A131) (see Figures 192, 193). From the selection of these activities, apparel associates could have interpreted the word *product* in the maintainability definition as *apparel line*. With this interpretation, the maintainability definition would read: DFLC-M is the consideration of the actions necessary to retain or restore an apparel line to a desired condition.

Early (1) DFLC-M activities selected by apparel associates are identifying piece goods, testing piece goods, and specifying garments (e.g., A5111, 5214, A33112) (see Figure 191). Middle (2) DFLC-M activities selected are to implement special operations and create carry-over garments (e.g., A4424, A43) (see Figures 190, 192). The only late (3) DFLC-M activity chosen by the apparel associates is to proof patterns (i.e., A434) (see Figure 190). The dominant trend for the change in sequence in apparel activities from the *as is* environment to the *to be* environment is shown in Table 10. The apparel

associates' selection of activities indicates that apparel activities which identify, test, and specify raw materials and garments could be conducted earlier in the process.

Table 10

An Overview of DFLC-M Apparel Activities Changes Between the *As Is* and *To Be* Environments

DFLC-M: Middle and Late *As Is* Apparel Activities that Shifted to Early *To Be* Activities	
Activity	Functional Activity Title
A33111	Develop full fashion knitting specifications (FFK)
A33112	Develop flat knitting specifications (FFK)
A5111	Identify piece goods
A5214	Test textile piece goods

Design for Cost Apparel Activities

Apparel activities in DFC are from two *as is* environment functional areas: create garment pattern and prototype (A4) and set production specifications (A5). DFC is defined as designing a product to a set target cost (Crow, 1992). Some apparel activities selected by apparel associates support the DFC definition. The apparel activities that support the DFC definition are conducting a pricing analysis, styling art to meet a specific price structure, and negotiating fabric costs (i.e., A53444, A2312, A5121) (see Figures 195, 199). Other DFC apparel activities selected by apparel associates are marker activities and garment cost calculation (e.g., A5432, A53441) (see Figure 197, 198). DFC apparel activities selected for marker development are to calculate or increase fabric efficiency by laying a costing marker and evaluating fabric utilization (e.g., A5432, A5433) (see Figure 197). The apparel activities selected by apparel associates for garment cost issues are to evaluate profit margins, price the apparel line, calculate first costs, and

calculate regular costs (e.g., A53443, A53446, A1616, A53441) (see Figures 195, 197, 198).

The apparel associates selected fabric cost considerations as early (1) DFC activities (e.g., A2312) (see Figure 199). Most DFC activities were middle (2) *to be* activities. The apparel activities selected by apparel associates are for costs, margins, marker efficiency, and prices. The specific cost activities include calculating regular costs and reviewing cost sheets (e.g., A53441, A53445) (see Figure 198). A marker efficiency activity is checking markers for fabric utilization (A5433). Some pricing activities noted are to conduct a pricing analysis and price the line (e.g., A53446, A53444) (see Figures 195, 197). The apparel associates selected determining sample yardage quantity as a late (3) cost activity (e.g., A512) (see Figure 196).

Table 11 shows the dominant trend for the change in sequence in DFC apparel activities from the *as is* environment to the *to be* environment. All of the conduct costing activities (A5344) shown as late activities in the *as is* environment moved to middle activities in the *to be* environment. The earlier calculation of cost is in concert with Turino's (1992) DFC explanation in which the design team predicts price estimates and product profitability during the design phase (e.g., A53446, A53443) (see Figure 195).

Table 11

An Overview of DFC Apparel Activities Changes Between the *As Is* and *To Be* Environments

DFC: Late *As Is* Apparel Activities that Shifted to Middle *To be* Activities	
Activity	Functional Activity Title
A5121	Negotiate sample fabric prices & cost assignment
A5123	Generate sample purchase order
A53441	Calculate regular cost
A53442	Calculate sample direct & indirect costs
A53443	Calculate profit margins
A53444	Conduct retail pricing analysis
A53445	Review cost sheets
A53446	Price the line
A5433	Check marker & evaluate fabric utilization
A5432	Lay sample costing marker
A5434	Approve marker

Summary of CE Apparel Activities

The findings on the *to be* environment show that the apparel activities in the *as is* environment did not remain sequential. Rather, within the CE conceptual statements, many apparel activities have moved from early to late, late to middle. Apparel activities crossed over functional areas described in the *as is* environment as create apparel line (A1), develop colors and prints (A2), implement fabric and special operations (A3), create pattern and prototype (A4), set production specifications (A5), and produce samples (A6). The movement of activities supports the CE design maturity curve concept. Many of the *to be* environment design activities within DFQ, DFLC-R, and DFLC-I moved to a later stage than their position in the *as is* environment. Apparel activities within DFM and DFC moved to an earlier stage, promoting the idea that manufacturing and costing decisions could be made at an earlier stage.

To Be Environment Potential Process Performance Improvement

The narrative on projected process performance improvements is based on results of a questionnaire that was given to a focus group of seven apparel associates from two companies in the sample. The apparel associates in the focus groups were involved with strategic planning and had a holistic knowledge of the design and product development processes. Since CE implementation was beyond the scope of the present study, the apparel associates were asked to project the use of the CE apparel model in the future to identify whether there is potential process performance improvement in the *to be* environment. The apparel associate focus group responded to the questions using their judgment and industry experience with the *as is* environment.

The apparel associates studied the *to be* $IDEF_0$ posters while responding to potential process performance questions that were open-ended and had a nominal scale rating. The $IDEF_0$ posters had the *to be* environment rearrangement of apparel activities. The questionnaires were directed at whether the *to be* environment activity rearrangement could potentially improve time-to-market, avoid excess cost, or improve process quality. The first three questions in the questionnaire were designed to ask overall potential process performance evaluation. The next seven questions were designed for the apparel associates to evaluate whether inclusion of multi-disciplinary teams potentially improves time-to-market, avoids excess cost, or improves process quality. The apparel associates rated the *to be* environment for potential process performance using a nominal scale of 0-10. The scale was divided into four sections: no improvement (0-2), little improvement (3-4), moderate improvement (5-7), and good improvement
(8-10).

Potential for Time-to-Market Improvement

The time-to-market question was based on CE authors' predictions that CE implementation reduces product development time (Rosenblatt and Watson, 1991; Syan, 1994). The apparel associates were asked the following question: "It was indicated in the current process the ability to stay on calendar was very difficult. In the new process do you think that time, or the flow of activities has potential for good improvement, moderate improvement, little improvement, or no improvement?" The findings indicated that the apparel associates had varied opinions on whether the flow of activities would improve time-to-market in the *to be* environment. Apparel associates' responses for the *to be* environment ranged from having no improvement to having moderate improvement from the *as is* environment. The average response across the seven respondents is in the third quartile indicating moderate time-to-market improvement. An advantage of the *to be* environment noted by an apparel associate is, "Anytime we review and analyze our processes and make adjustments for improvement is always a plus." Two apparel associates had differing opinions: One apparel associate felt an even flow of decisions would help improve the process, while the other felt the *to be* environment did not address some factors that impact everyday processes. The comments from the apparel associates address Maddux and Souder's (1993) claim that CE requires organizational change and requires management to provide an environment that allows for the exchange of information.

The researcher created a survey kit for the apparel associates to answer questions on whether a multi-disciplinary team could improve time-to-market. The survey kit consisted of $IDEF_0$ diagrams, $IDEF_0$ posters, and a questionnaire. The researcher first compiled the results of the enabling technology questionnaire. Based on these results, the researcher drew $IDEF_0$ diagrams that identified multi-disciplinary team members for each

CE conceptual statement (e.g., design for enabling technology). The apparel associates referred to the $IDEF_0$ diagrams, with the team members identified, and the $IDEF_0$ posters, with the functional activities, to answer the seven questions. To evaluate whether time-to-market could improve, the responses are based on the combined response of seven questions from the apparel associate focus groups. The same question was repeated for each CE conceptual statement. The questions stated, "Based on your experience, how do you feel that the inclusion of the virtual team could potentially improve the activities for xxx (i.e., DFQ, DFET, DFM, DFLC-R, DFLC-I, DFLC-M, or DFC)?" The apparel associates' average response for whether inclusion of a multi-disciplinary team could improve time-to-market is the third quartile (i.e., moderate improvement) for DFQ, DFET, DFM, and DFC apparel activities, indicating moderate time-to-market improvement. The apparel associates' response for the inclusion of a team supports Blaich and Blaich's (1993) ideas that for design to be integrated with product development requires the use of multi-disciplinary teams in order to obtain early and continuous product design decisions from market research through market launch. The apparel associates' average response for whether the inclusion of a multi-functional team would improve time-to-market is in the 2nd quartile (i.e., little improvement) for DFLC-R and DFLC-I apparel activities. The apparel associates average response indicated that there was no time-to-market improvement (i.e., 1st quartile) for DFLC-M apparel activities.

Apparel associates' written responses for the team related time-to-market questions were mixed for potential improvement in the *to be* environment. Some felt there would be a time-to-market improvement while others felt that the *to be* environment appeared more time-consuming. One apparel associate added that the *to be* environment resembled the Japanese manufacturing practices in lengthening time. Four apparel

associates wrote that interactive team participation would reduce product development cycle time. One apparel associate noted, "I think time will be saved with more people involved and aware up front and hopefully save things being done twice." Another apparel associate emphasized this thought with, "Up front planning saves time on the back end." One apparel associate commented that more textile representative involvement would reduce the time to develop new fabrics. Two apparel associates commented that the *to be* environment may be more time consuming, because advance planning appears very intense. One apparel associate noted that time could be improved by limiting the number of people involved.

Potential for Excess Cost Reduction

The excess cost question was based on the premise that the CE approach reduces costs from having fewer defects, a reduced amount of scrap, and reduced rework (Lawson & Karandikart, 1994). The apparel associates were asked the following question: "Some activities (e.g., rework, overtime) increase the cost of the current product development process. In the new process do you think that avoiding cost has potential for good improvement, moderate improvement, little improvement, or no improvement?" The apparel associates' average response is in the third quartile, indicating moderate improvement that the *to be* environment could potentially avoid excess cost. Five apparel associates' written responses indicated that the *to be* environment could reduce costs. Three apparel associates commented that early planning, quick decisions, clear decisions, and review of processes could reduce costs. One apparel associate stated, "I believe reviewing and improving processes has a huge potential for cost savings, from the design process all the way through production."

The researcher used the same questionnaire described in time-to-market for the apparel associates to answer questions on whether a multi-disciplinary team could

improve excess cost. The survey kit consisted of $IDEF_0$ diagrams, $IDEF_0$ posters, and a questionnaire. The apparel associates referred to the $IDEF_0$ diagrams, with the team members identified, and the $IDEF_0$ posters, with the functional activities, to answer the seven questions. To evaluate whether excess cost could improve, the responses are based on the combined response of seven questions from the apparel associate focus groups. The same question was repeated for each CE conceptual statement. The question asked was, "Based on your experience, how do you feel that the inclusion of the virtual team could potentially improve the activities for xxx (i.e., DFQ, DFET, DFM, DFLC-R, DFLC-I, DFLC-M, or DFC)?" For inclusion of a multi-disciplinary team, the apparel associates' average response is in the third quartile indicating a moderate reduction of excess cost for DFQ, DFET, DFM, DFLC-R, and DFC apparel activities. The apparel associates' average response for DFLC-I and DFLC-M apparel activities indicates there would be little improvement (i.e., second quartile) for reducing excess cost in these areas. One apparel associate's written comment stated that reducing product design cost could benefit with the specific activities within DFLC-I.

The written comments described below by six apparel associates indicated that costs could be reduced in the *to be* environment. Two apparel associates indicated that design for cost is helpful in developing new products. One apparel associate noted, "Designing for cost early in the game is a plus from start to finish." Two apparel associates indicated that if apparel activities are completed correctly the first time, costs would be saved, and especially by not doing the same work twice. One apparel associate stated, "Having the incentive and being more responsive to construction execution would improve cost." However, one apparel associate indicated that there would be little initial cost improvement due to the cost needed for training and equipment.

Potential for Process Quality Improvement

A company can lose significant revenue by product market delay (Carter and Stilwell-Baker, 1992). The apparel associates were asked the following question: "It was indicated in the current process that quality was decreased due to rush work and peaks and valleys of demand (e.g., producing samples). Do you think the rearranging of activities could create a better flow and has potential for good improvement, moderate improvement, little improvement, or no improvement?" Four apparel associates' opinions indicated that the flow of activities in the *to be* environment could improve process quality. The apparel associates' average response is in the third quartile indicating that there is potential for moderate process quality improvement. One apparel associate stated that their company was in the process of rearranging product development activities with the anticipation that process quality would be increased. Two apparel associates commented that early planning is critical and a better flow of activities helps apparel associates do their work right the first time, which avoids rework. One apparel associate commented, "A better flow would help things from falling through the cracks and help to do things right the first time." These comments emphasize a limitation of sequential manufacturing, described in the *as is* environment, that some work is missed and is a cause of rework. One apparel associate stated, "I believe a more consistent flow of activities would give all involved more time to do their job at a higher level of quality." This apparel associate's response supports Turino's (1992) opinion that the CE approach promotes the allocation of extra design time in order to create a successful product.

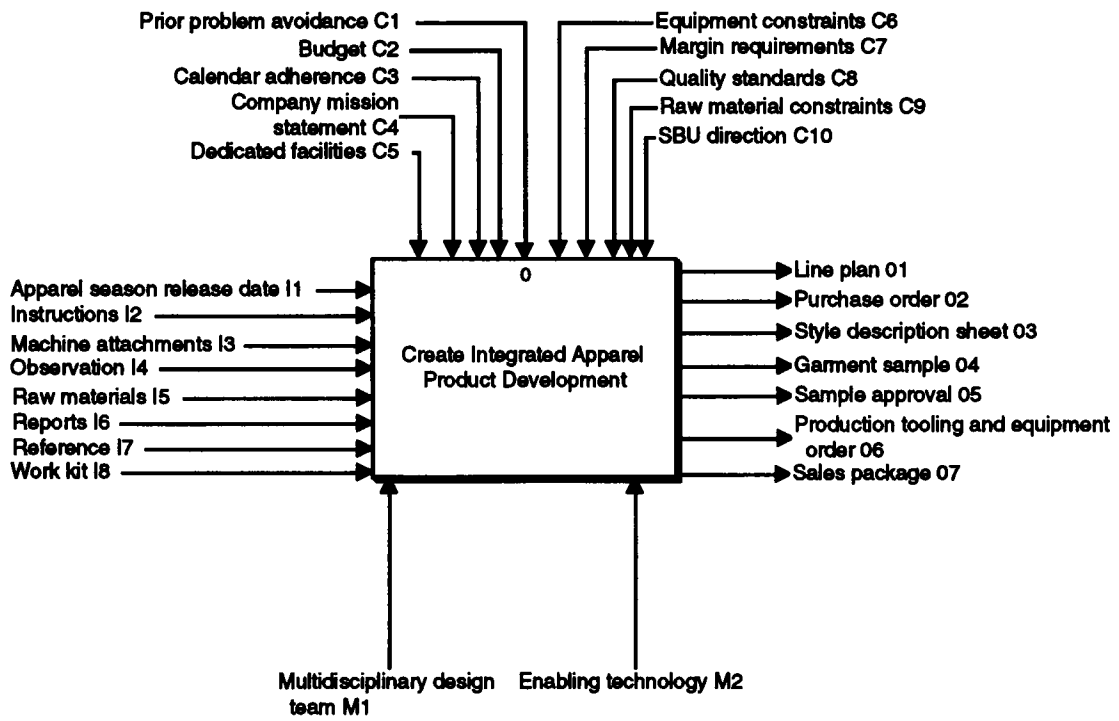
The researcher used the same survey kit described in time-to-market for the apparel associates to answer questions on whether a multi-disciplinary team could improve process quality. The survey kit consisted of $IDEF_0$ diagrams, $IDEF_0$ posters, and a questionnaire. The apparel associates referred to the $IDEF_0$ diagrams, with the team

members identified, and the $IDEF_0$ posters, with the functional activities, to answer the seven questions. To evaluate whether process quality` could improve, the responses are based on the combined response of seven questions from the apparel associate focus groups. The same question was repeated for each CE conceptual statement. The question asked was, "Based on your experience, how do you feel that the inclusion of the virtual team could potentially improve the activities for xxx (i.e., DFQ, DFET, DFM, DFLC-R, DFLC-I, DFLC-M, or DFC)?" The apparel associates indicated that the inclusion of a multi-disciplinary team would moderately improve (i.e., third quartile) process quality in conducting the apparel activities within DFQ, DFET, DFM, DFLC-R, DFLC-I, and DFC. One apparel associate commented that DFLC-M inclusion in the *to be* environment was questionable for process quality improvement.

Four apparel associates indicated that multi-disciplinary team involvement could improve process quality. One apparel associate stated, "Identifying print vendors, patterns, and engineering can benefit and offer quick technical input for execution of [the] product." This comment supports Pawar's (1994) explanation of the CE design team. Instead of a product design being one person's responsibility, CE uses a multi-disciplinary team to solve a design problem. One apparel associate commented, "Quality of work should improve since you will have more time to think through ahead of time and [can] execute properly." Three apparel associates noted that having manufacturing apparel associates involved would benefit the process, avoid manufacturing delays, and avoid creating mistakes. On having a multi-disciplinary team for DFLC-R apparel activities, one apparel associate commented, "This is one of the most exciting possibilities as far as creating vendor partnership. I see big potential for improvement in this area."

Summary of the *To Be* Environment Process Performance

The apparel associates' average overall response to the questionnaires indicates that the *to be* environment could moderately improve from the *as is* environment for time-to-market, excess cost, and process quality. The majority of apparel associates from the focus groups wrote that the inclusion of a multi-disciplinary team could improve time-to-market, avoid excess cost, and improve process quality. A quote from an apparel associate sums up multi-disciplinary team inclusion. "There is tremendous room for improvement here if we can get the team involved early in the process [to] reduce lead times and [have] more accurate forecasting." The apparel associates selection to include textile vendors as part of a virtual team supports the CE approach to include suppliers as members of multi-disciplinary CE teams.



Purpose: To create a *to be* integrated apparel product development process using the CE approach. The model shows the the functional activities and mechanisms that changed from the *as is* process.

Viewpoint: Ph.D. student/analyst perspective based on interviews of representatives actual apparel and textile firms

NODE: A-0

Figure 120. Top level drawing.

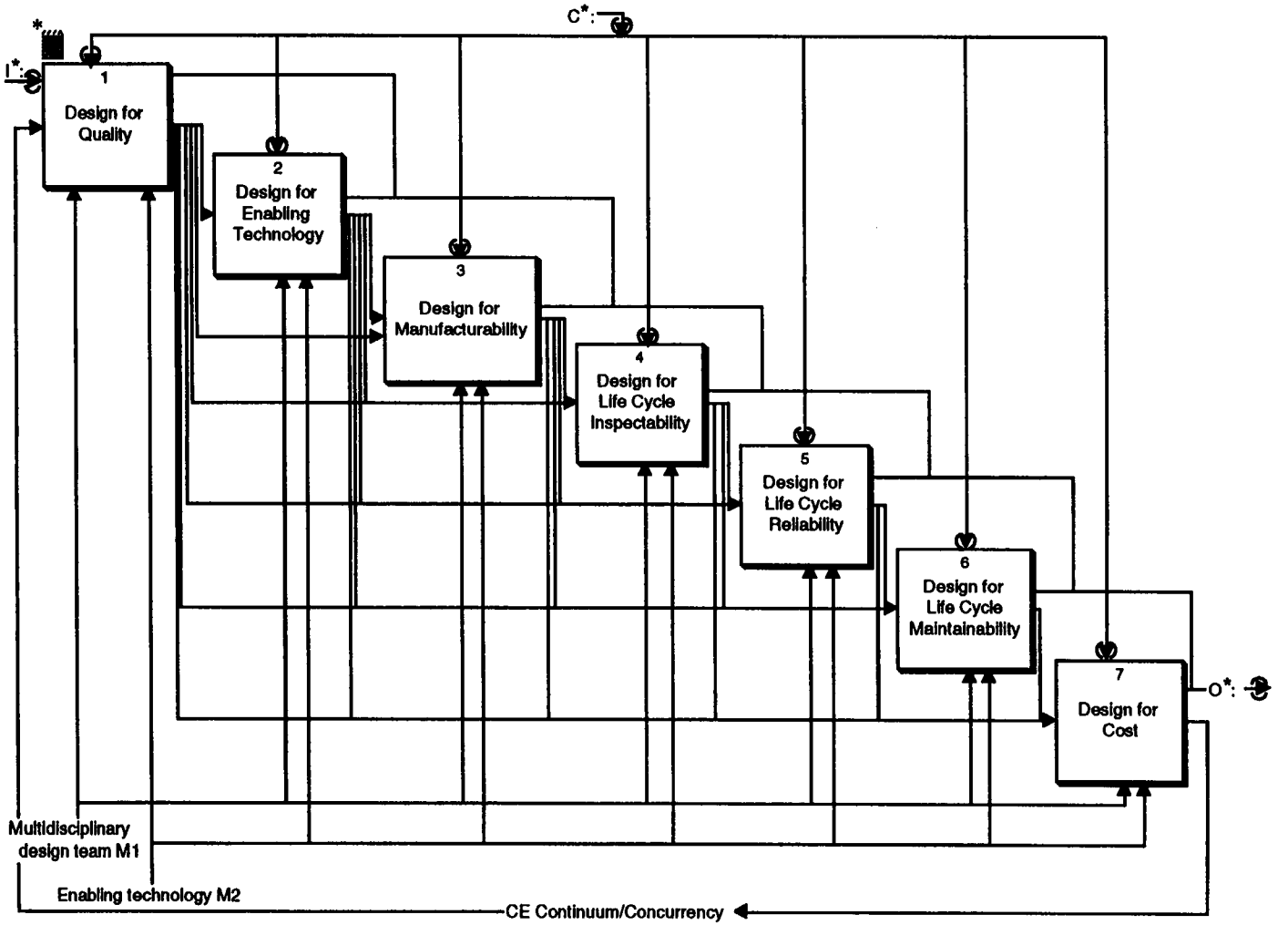


Figure 121. Create integrated apparel product development.

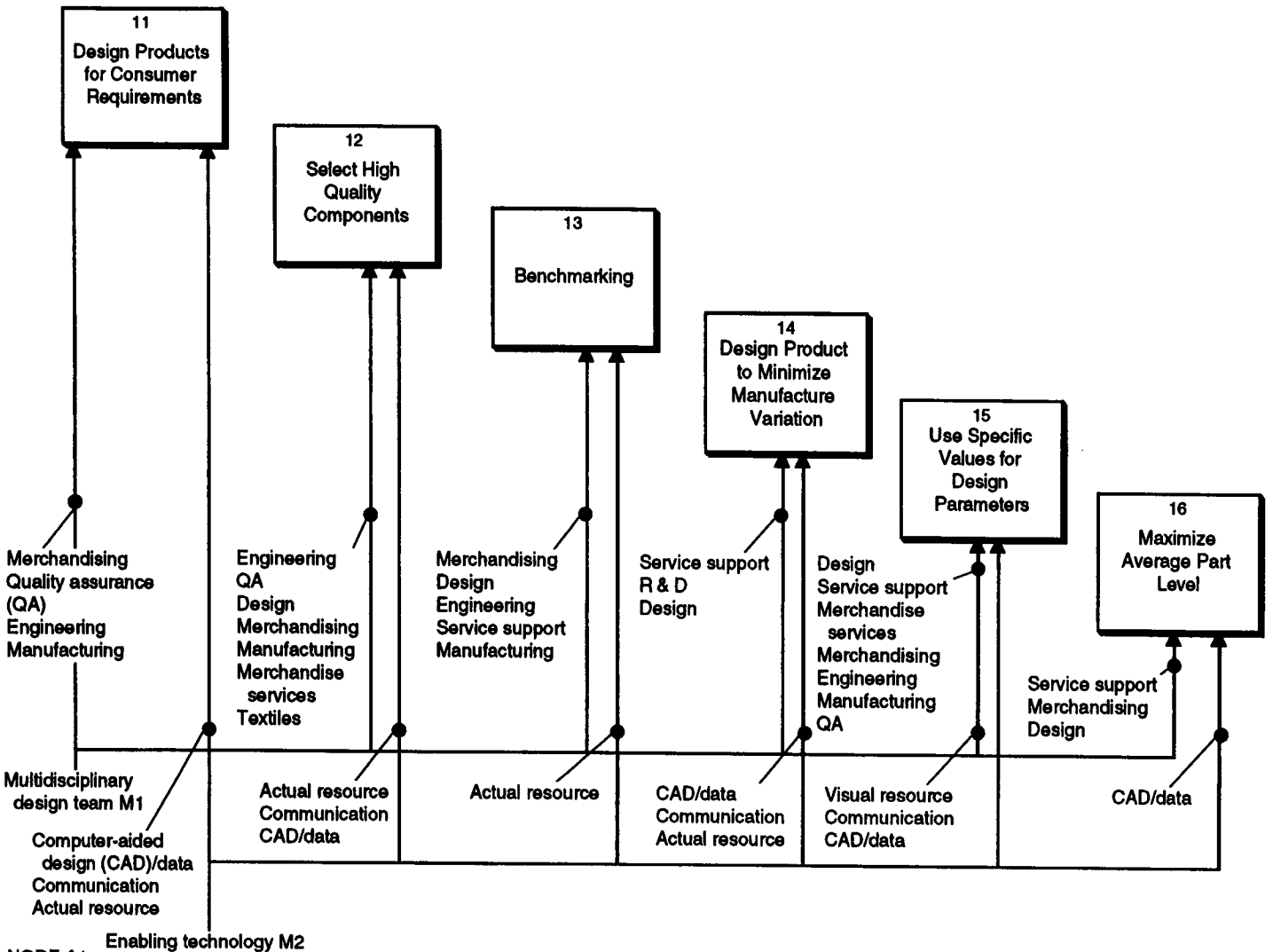
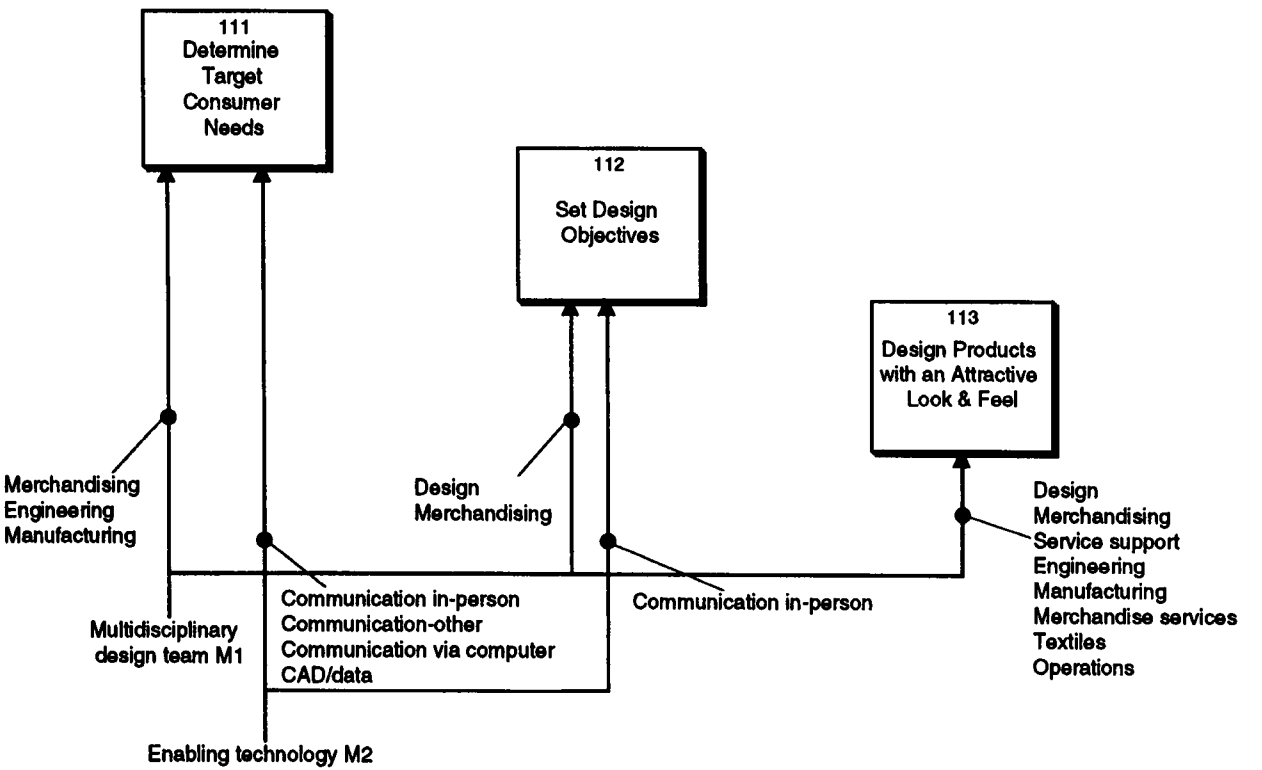
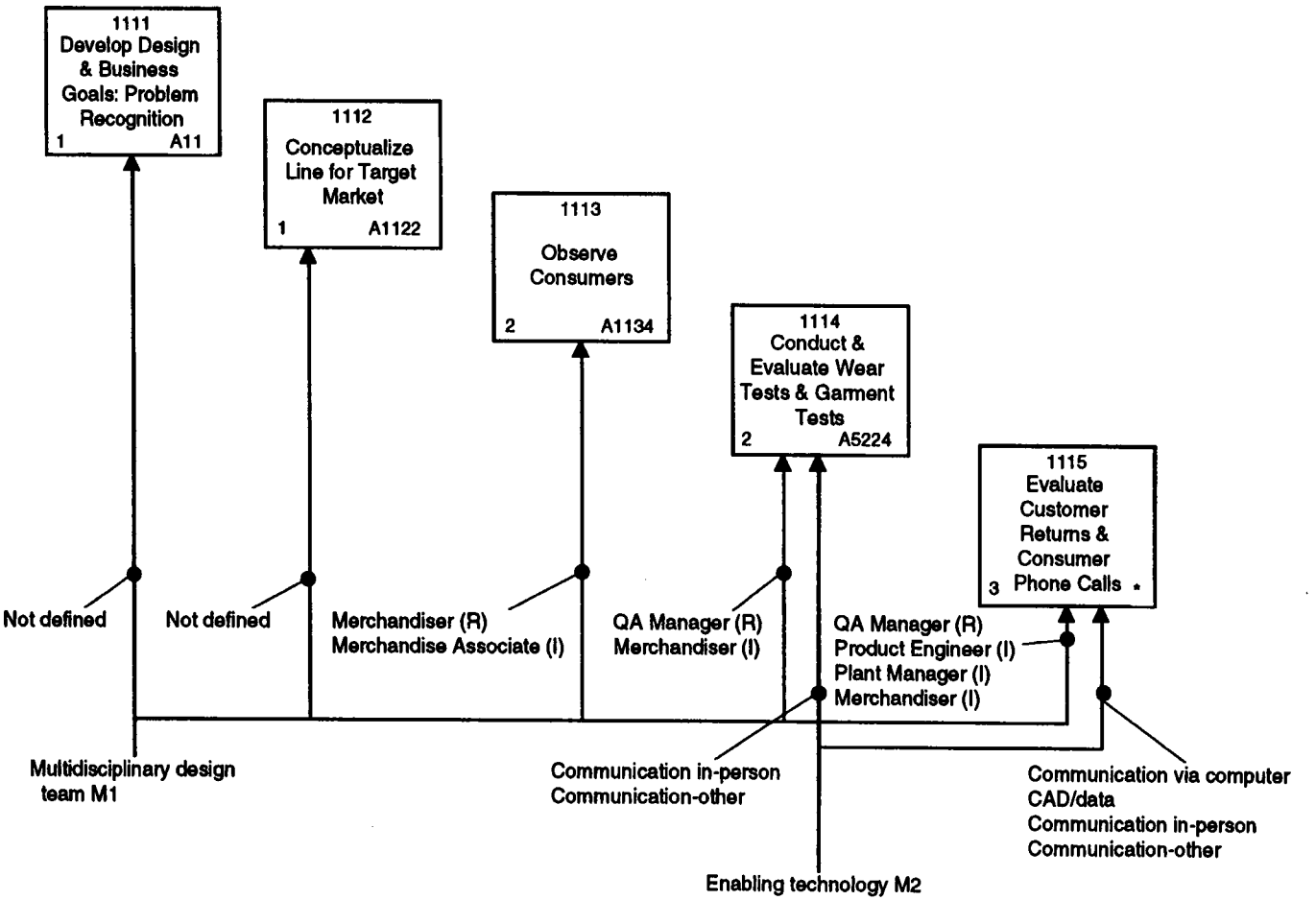


Figure 122. Design for quality.



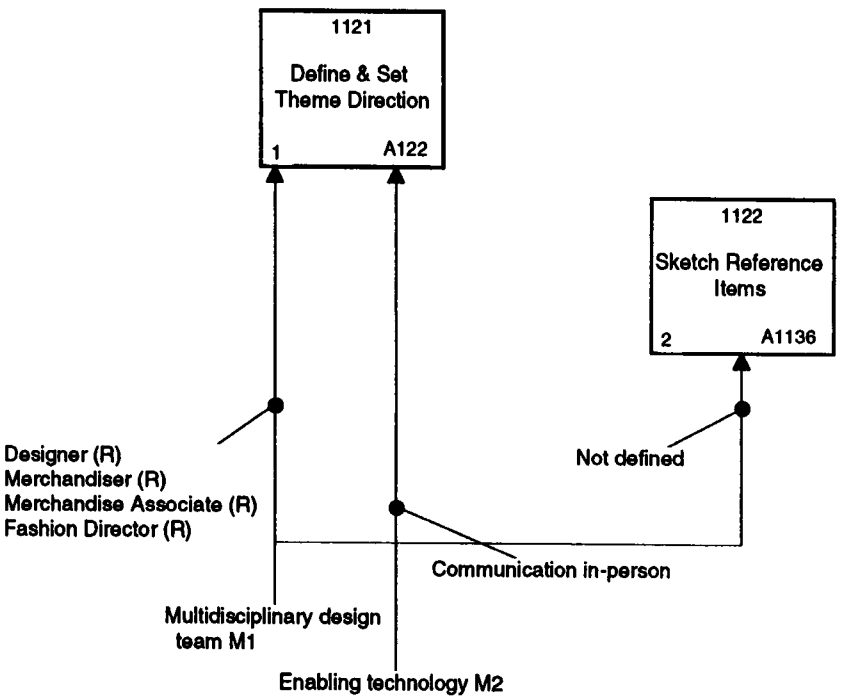
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Figure 123. Design products for consumer requirements.



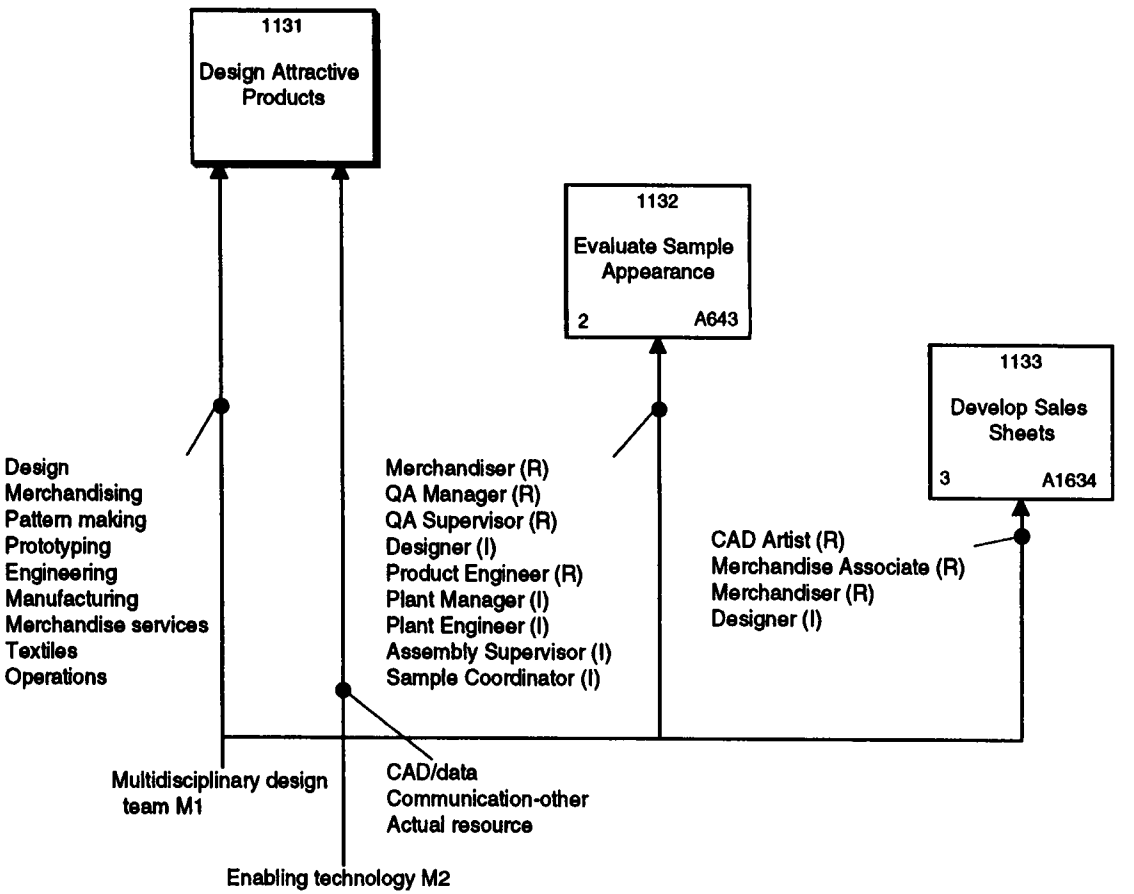
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Figure 124. Determine target consumer needs.



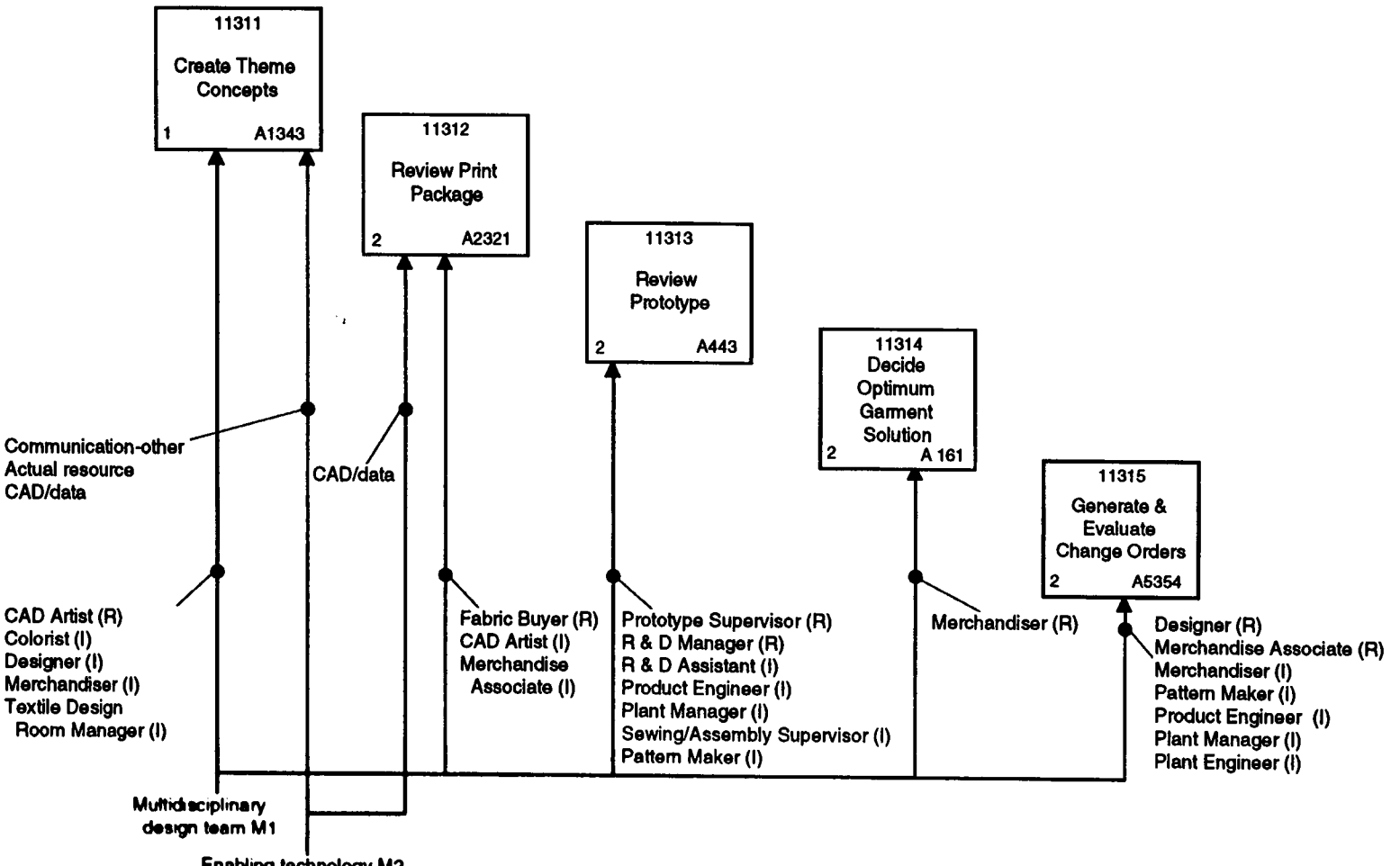
NODE: A112

Figure 125. Set design objectives.



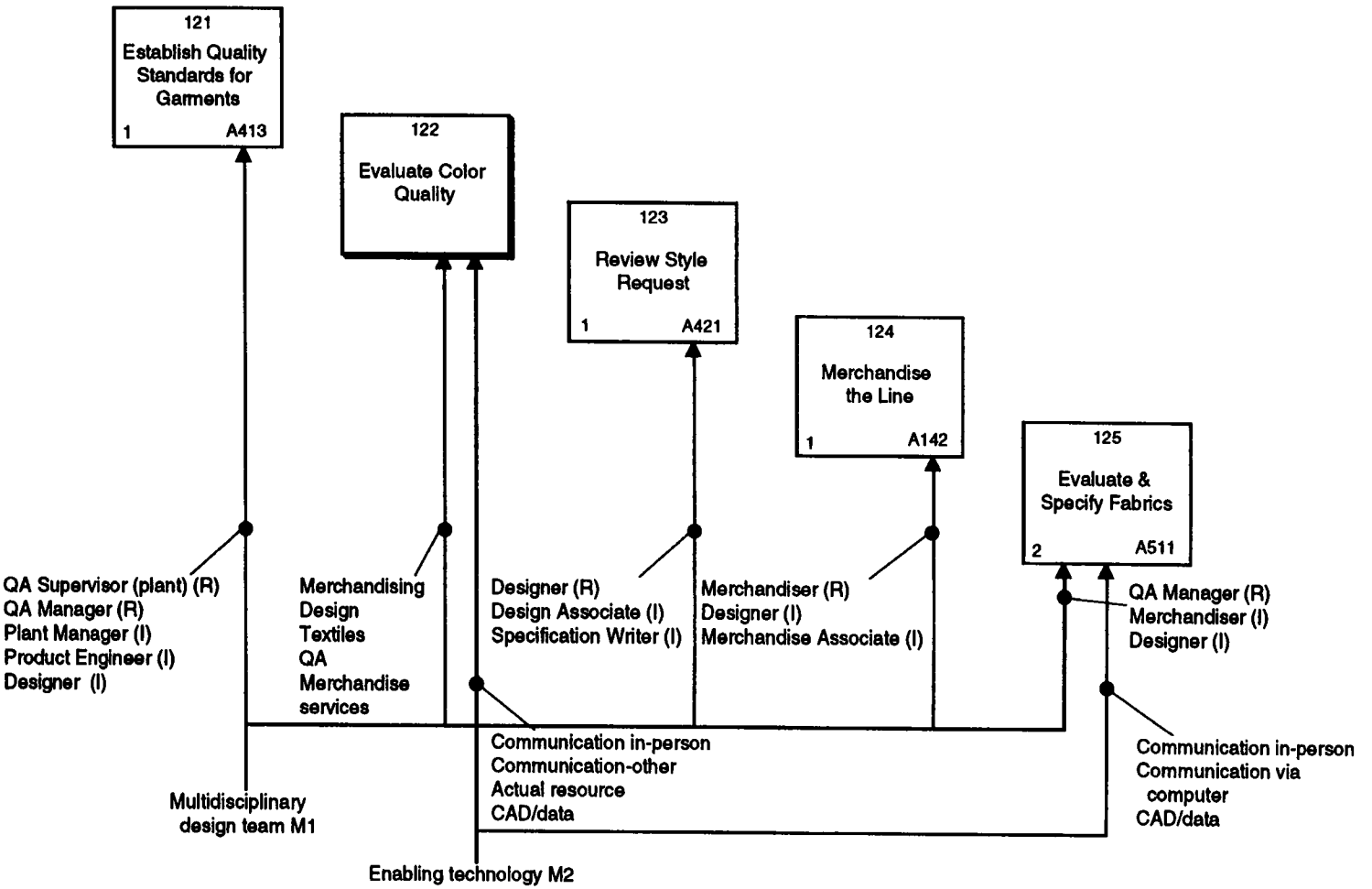
NODE: A113

Figure 126. Design products with an attractive look & feel.



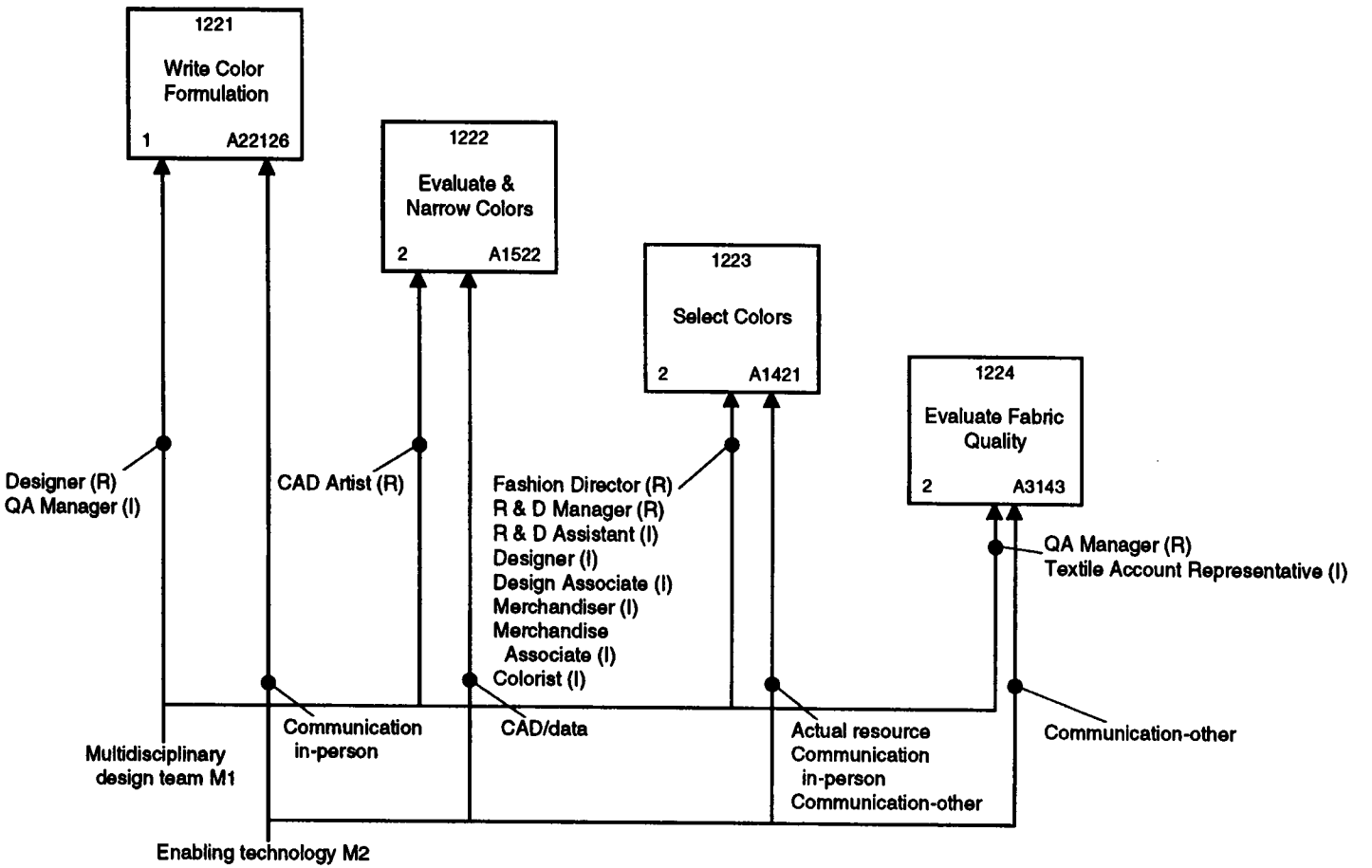
NODE: A1131

Figure 127. Design attractive products.



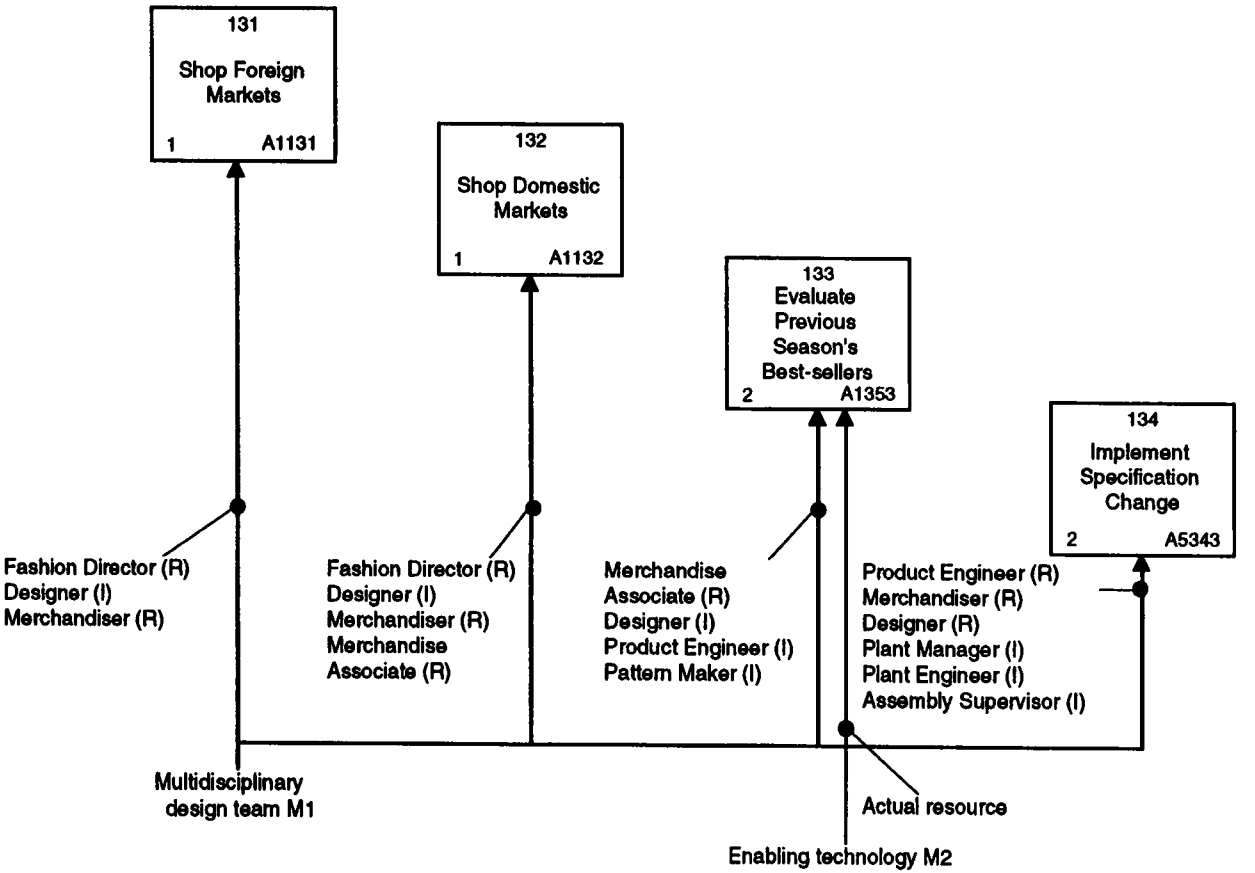
NODE: A12

Figure 128. Select high quality components.



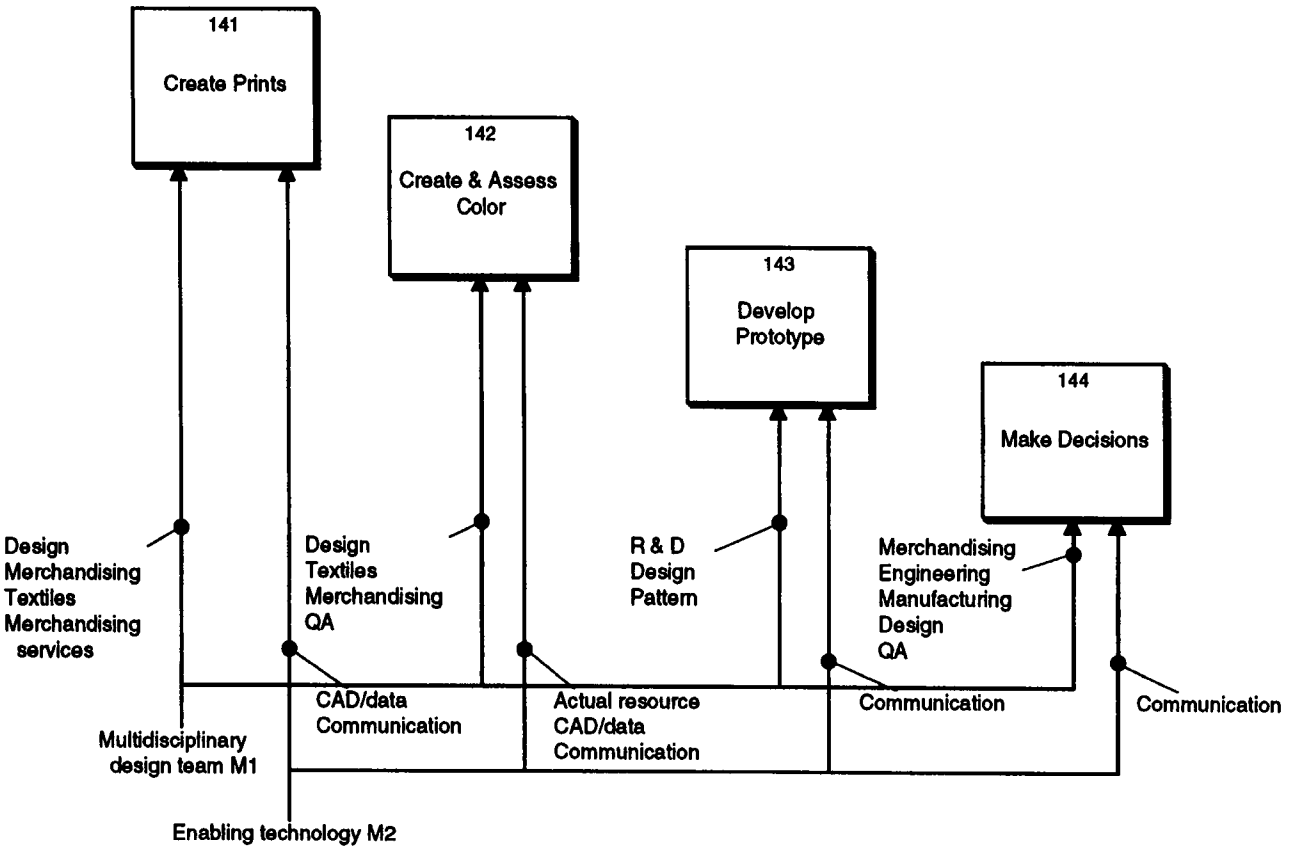
NODE: A122

Figure 129. Evaluate color quality.



NODE: A13

Figure 130. Benchmarking.



NODE: A14

Figure 131. Design product to minimize manufacture variation.

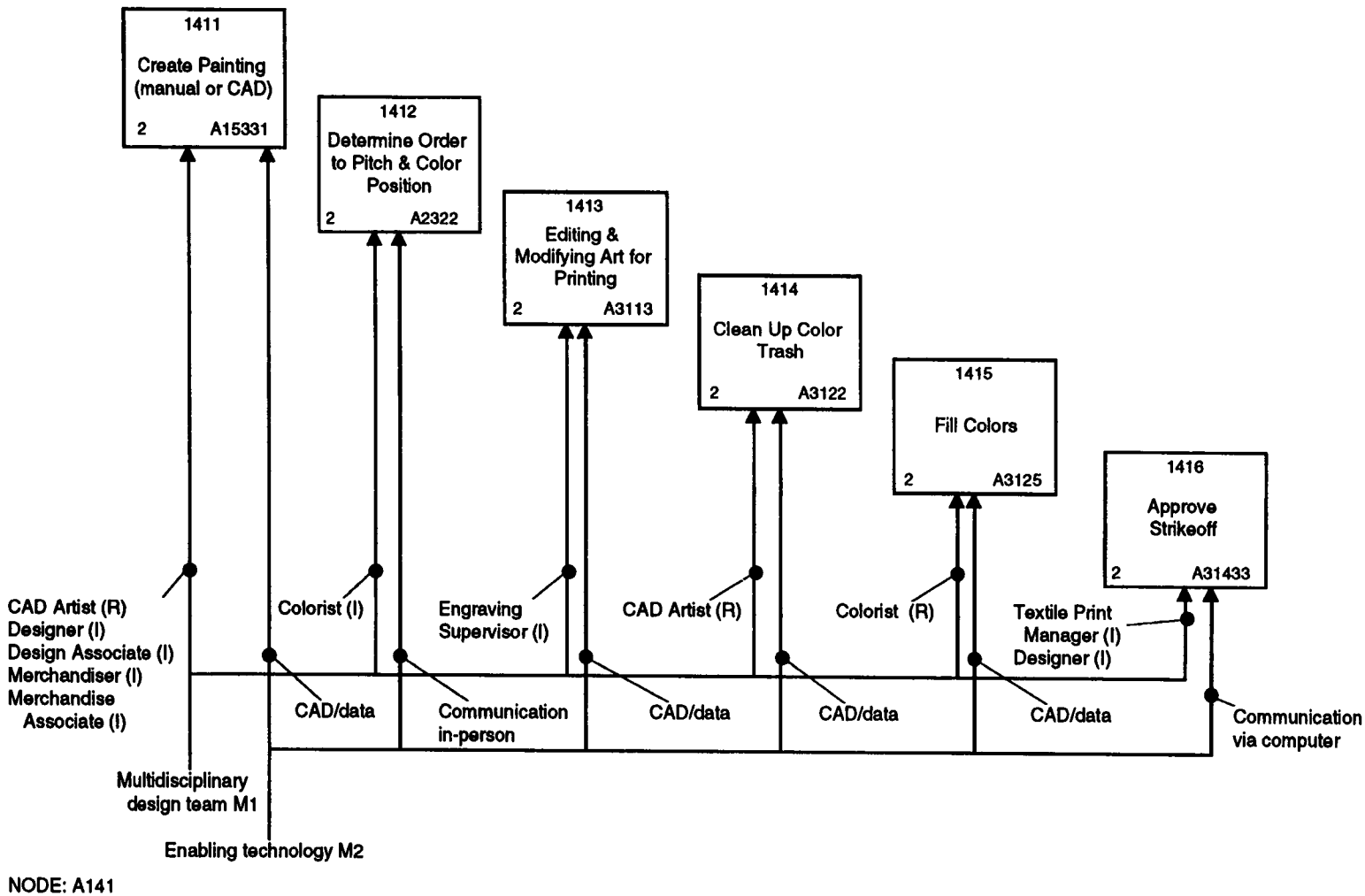
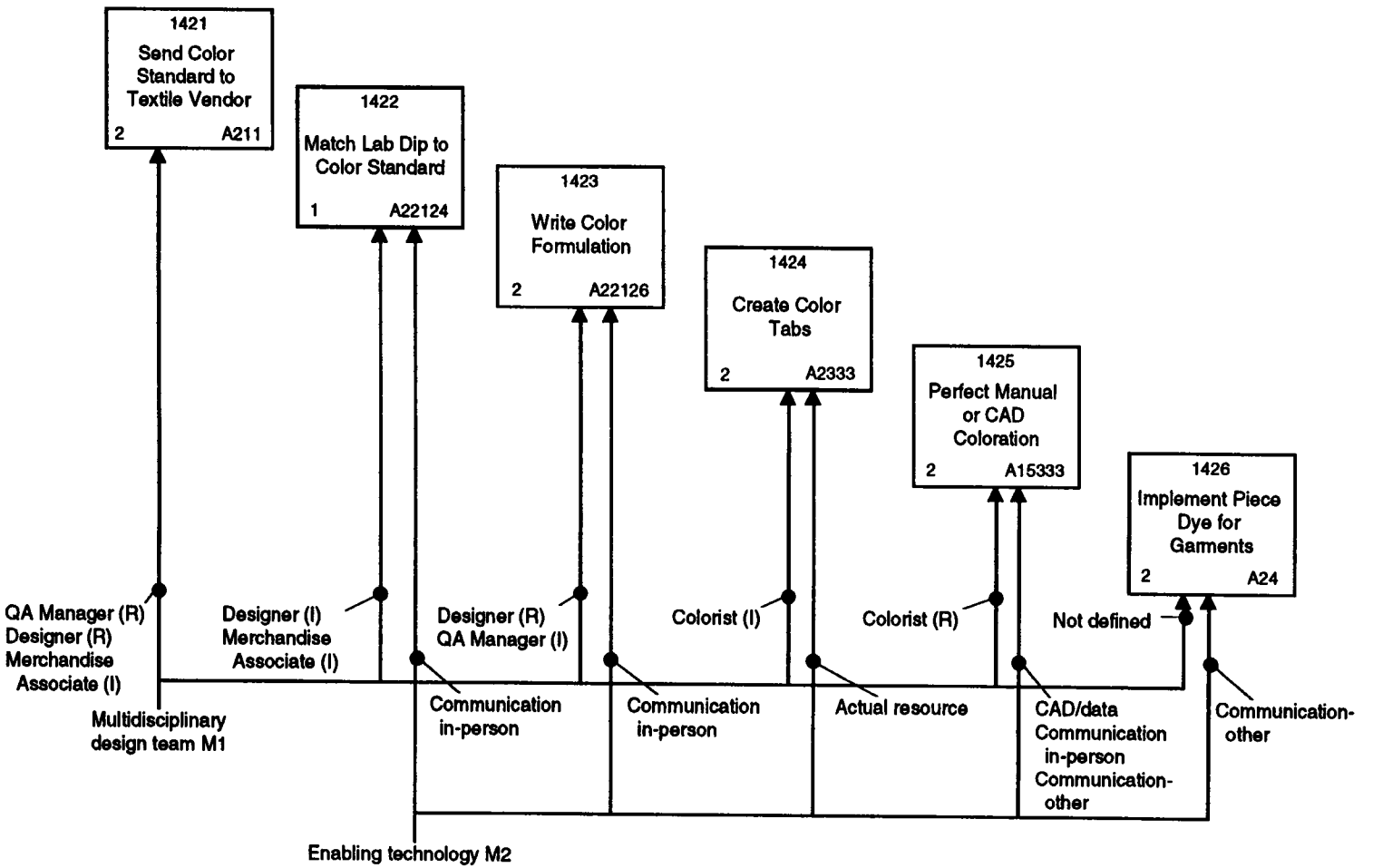
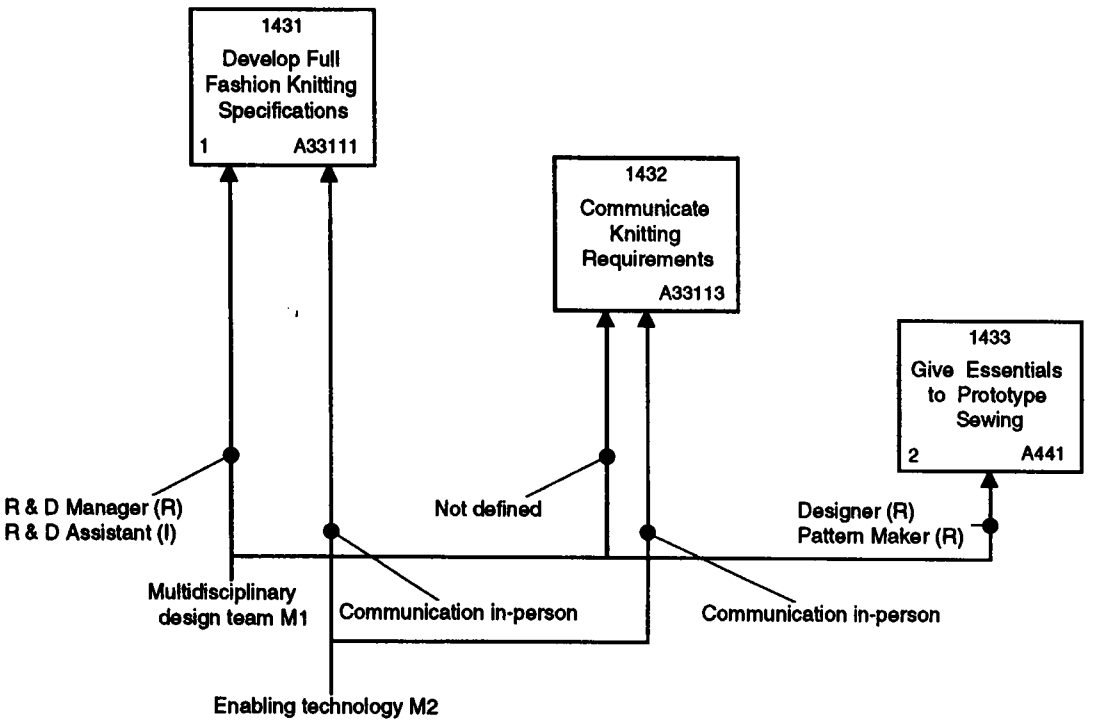


Figure 132. Create prints.



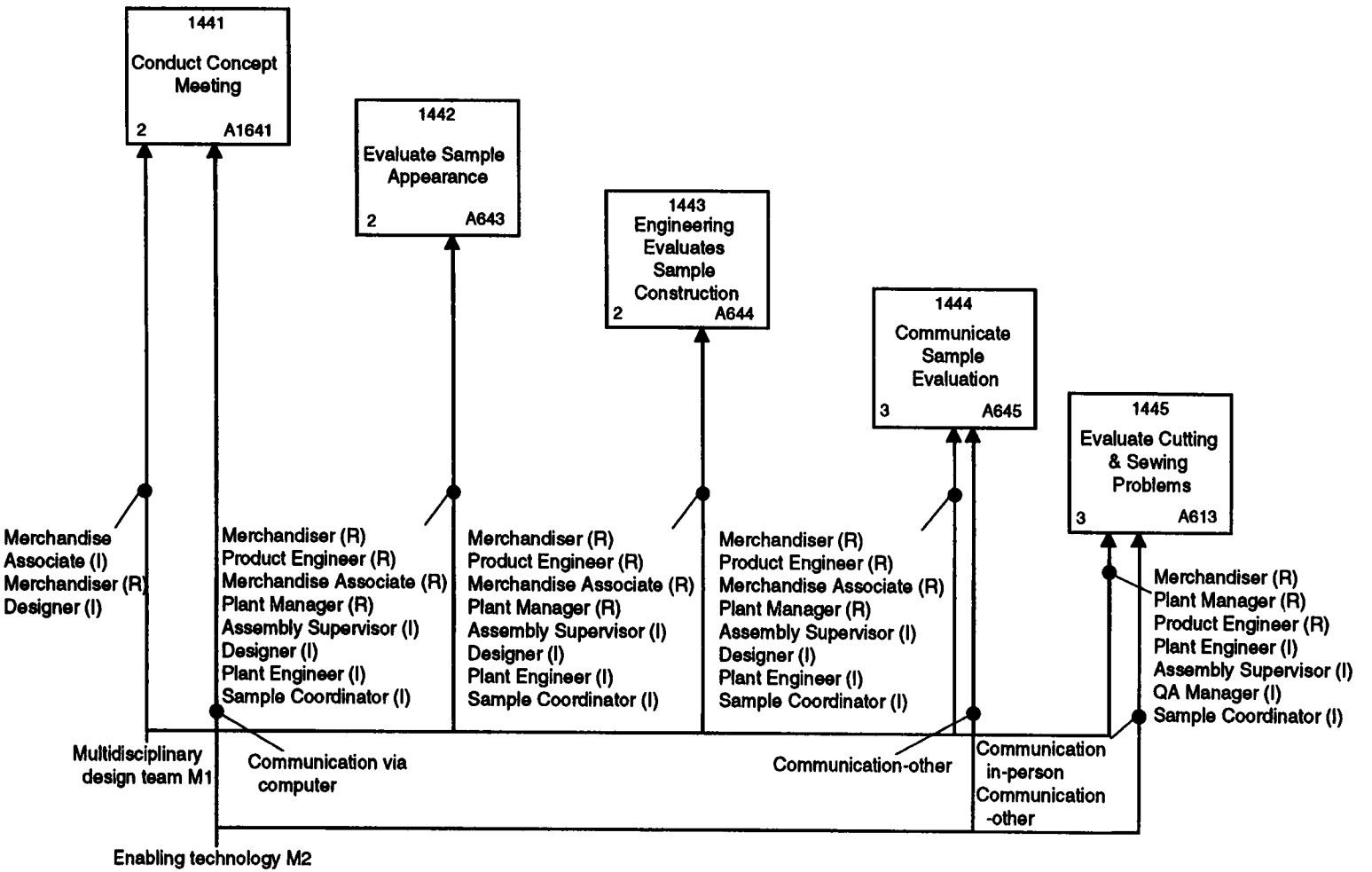
NODE: A142

Figure 133. Create and assess color.



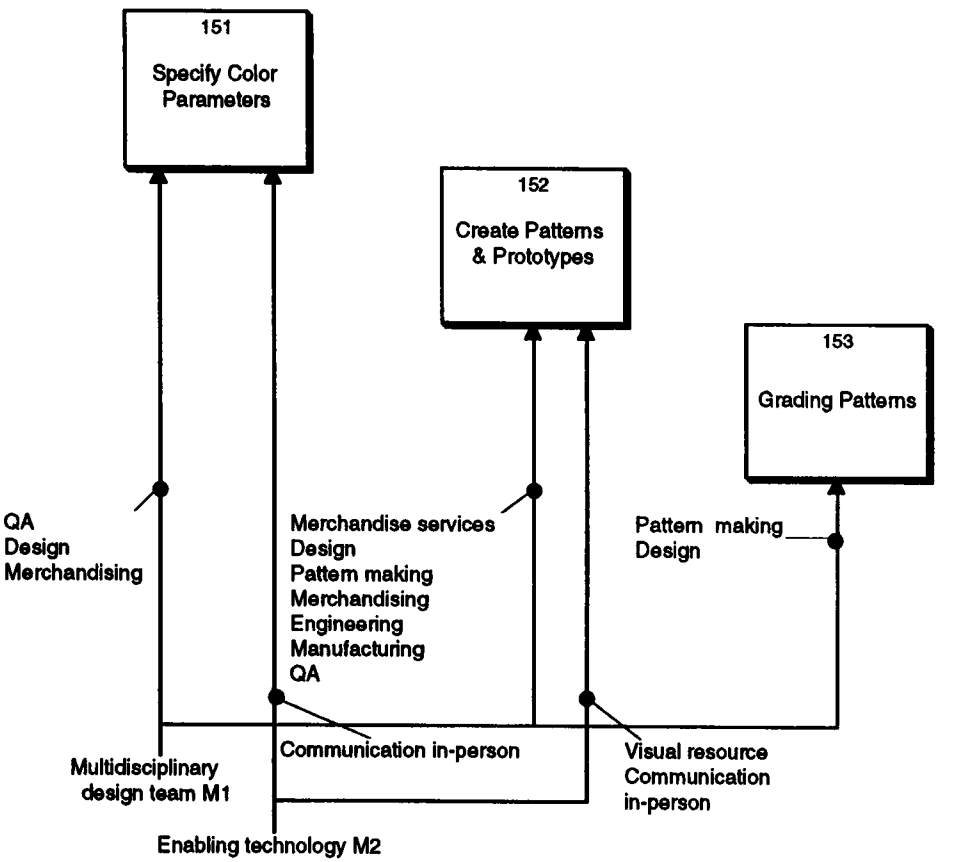
NODE: A143

Figure 134. Develop prototype.



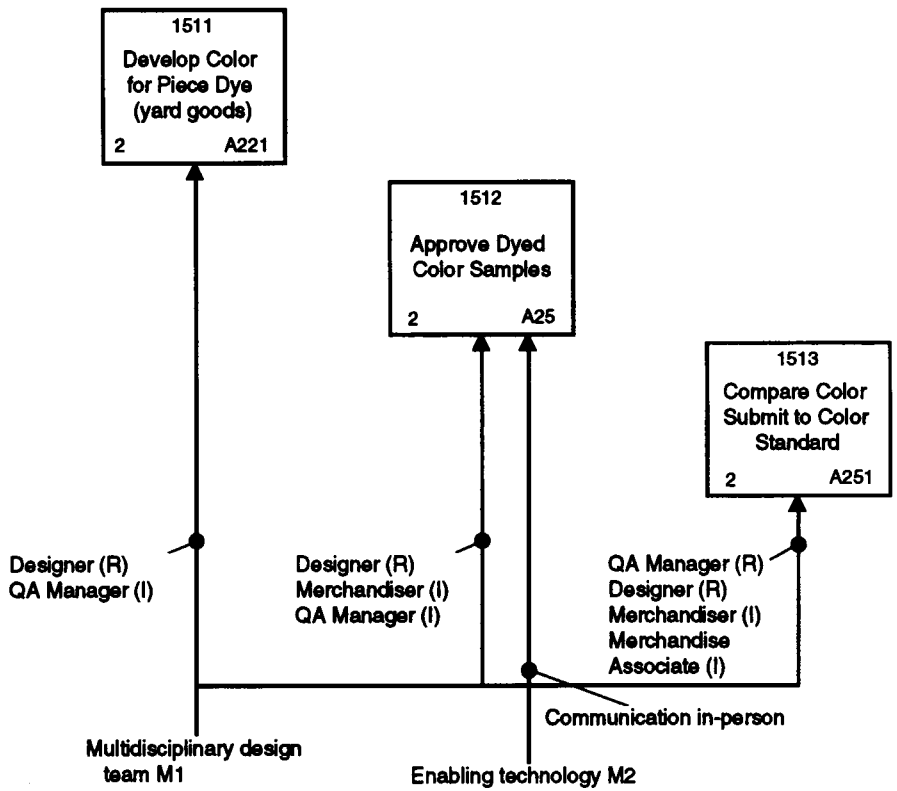
NODE: A144

Figure 135. Make decisions.



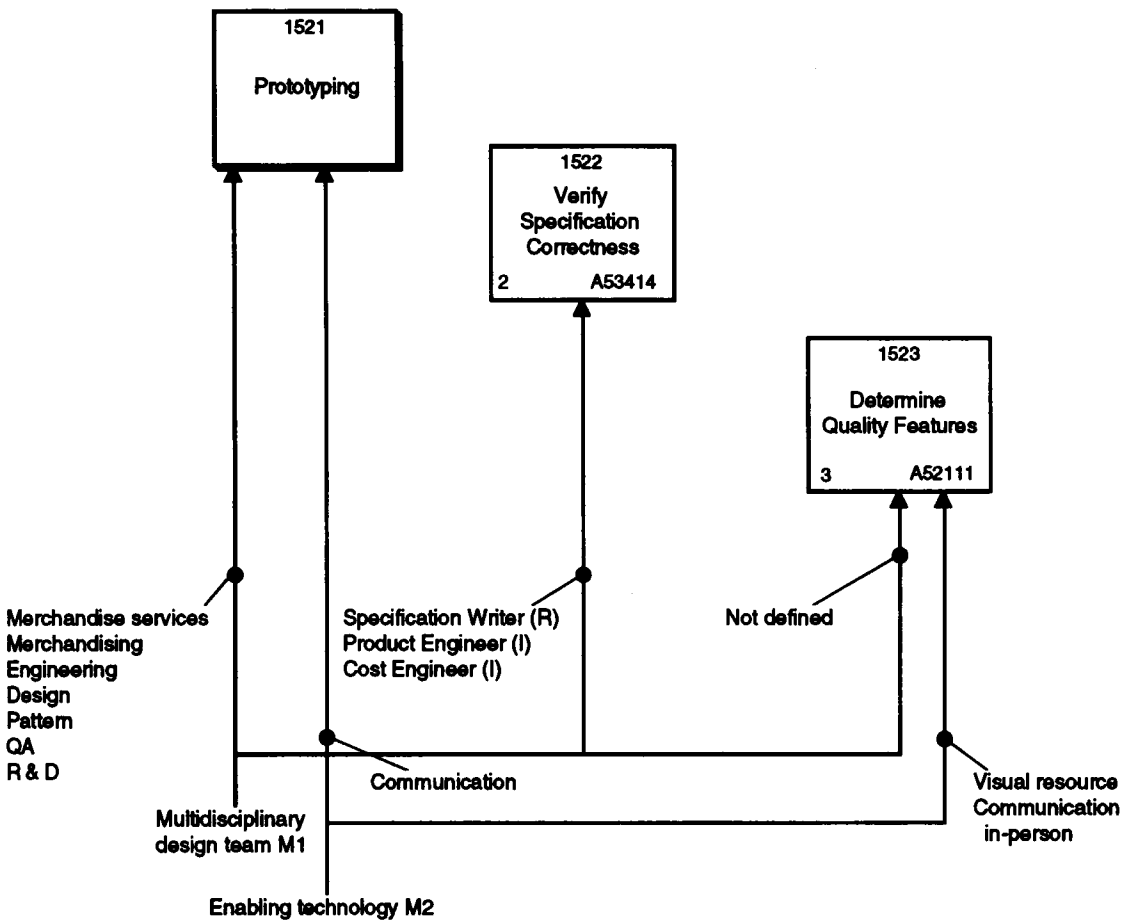
NODE: A15

Figure 136. Use specific values for design parameters.



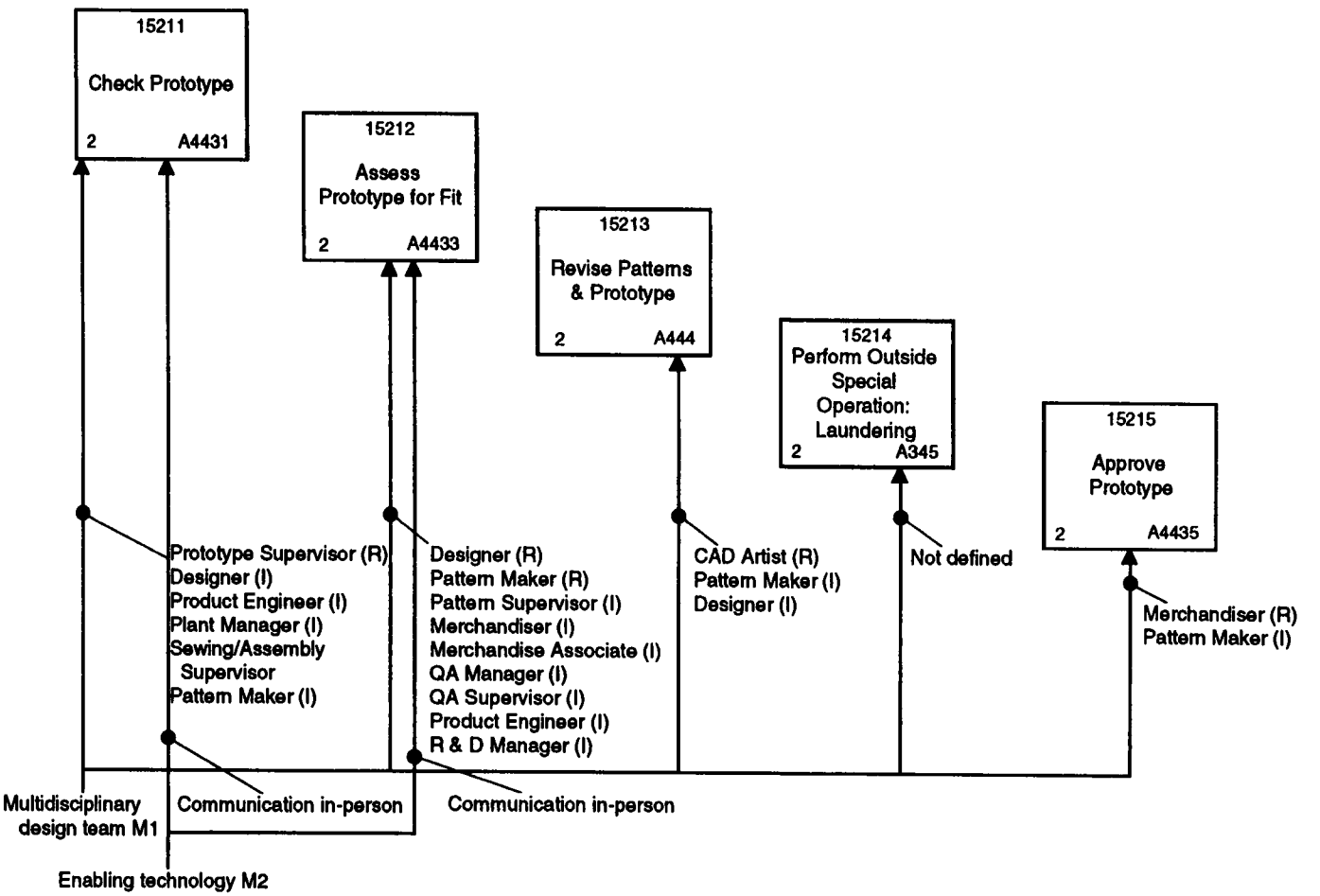
NODE: A151

Figure 137. Specify color parameters.



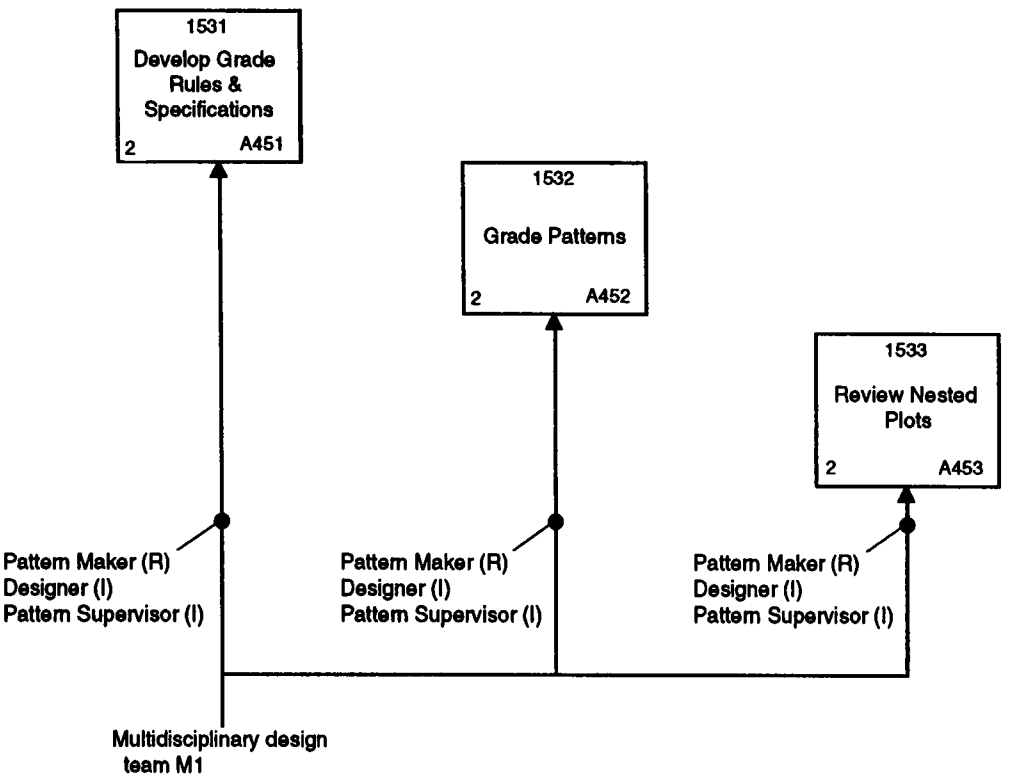
NODE: A152

Figure 138. Create patterns and prototypes.



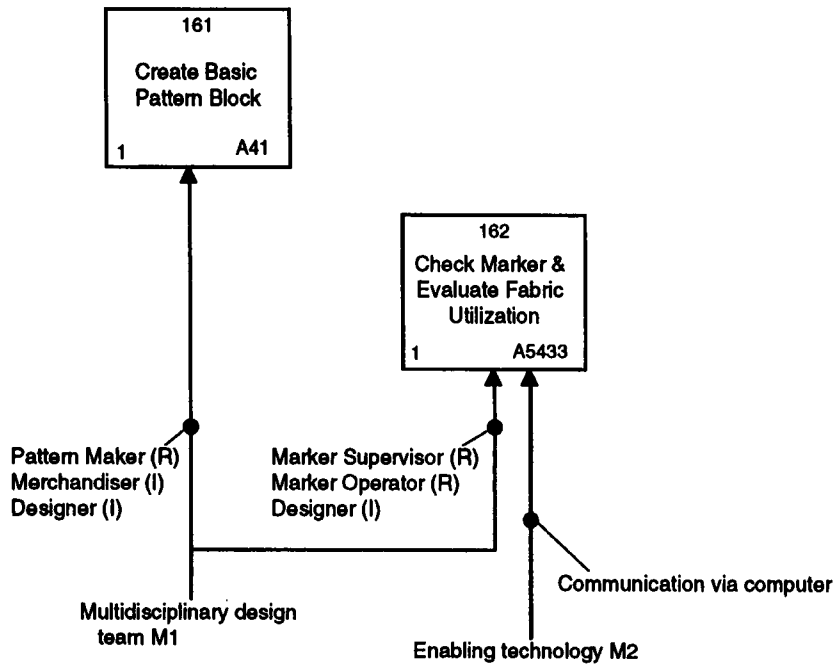
NODE: A1521

Figure 139. Prototyping.



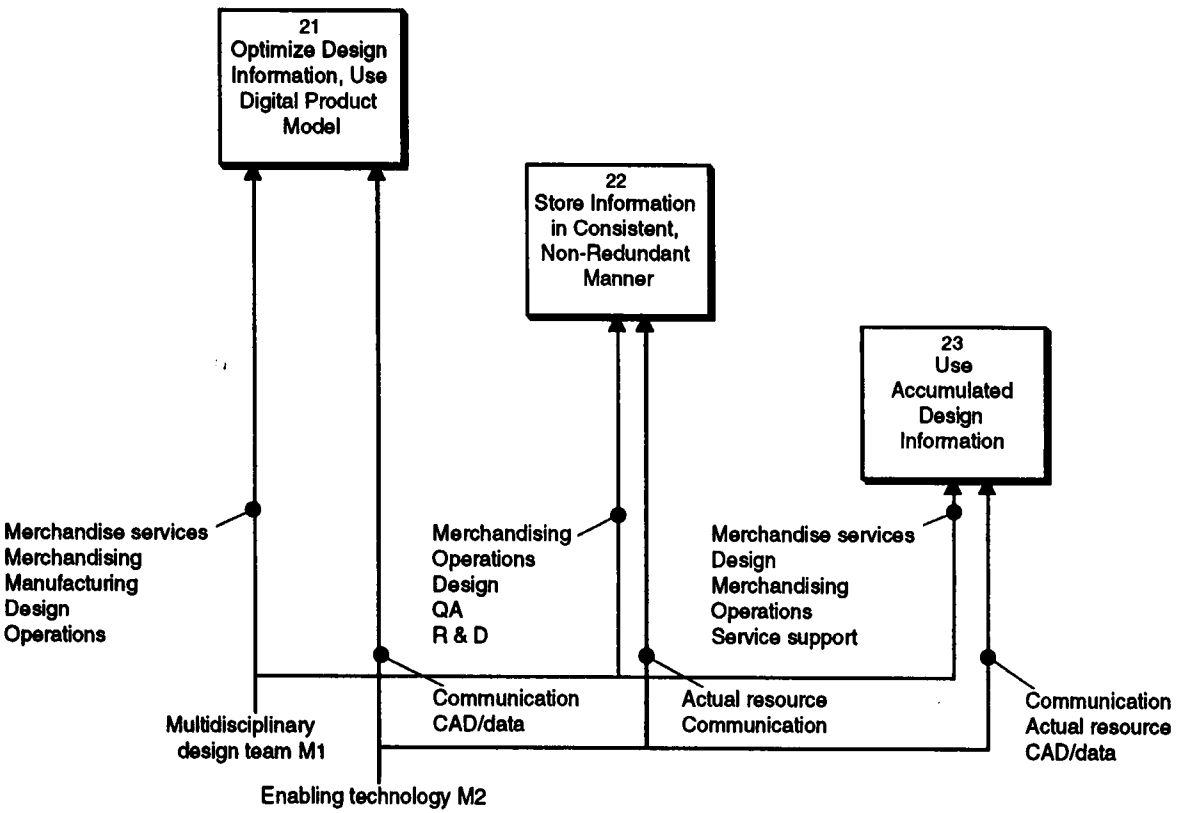
NODE: A153

Figure 140. Grading patterns.



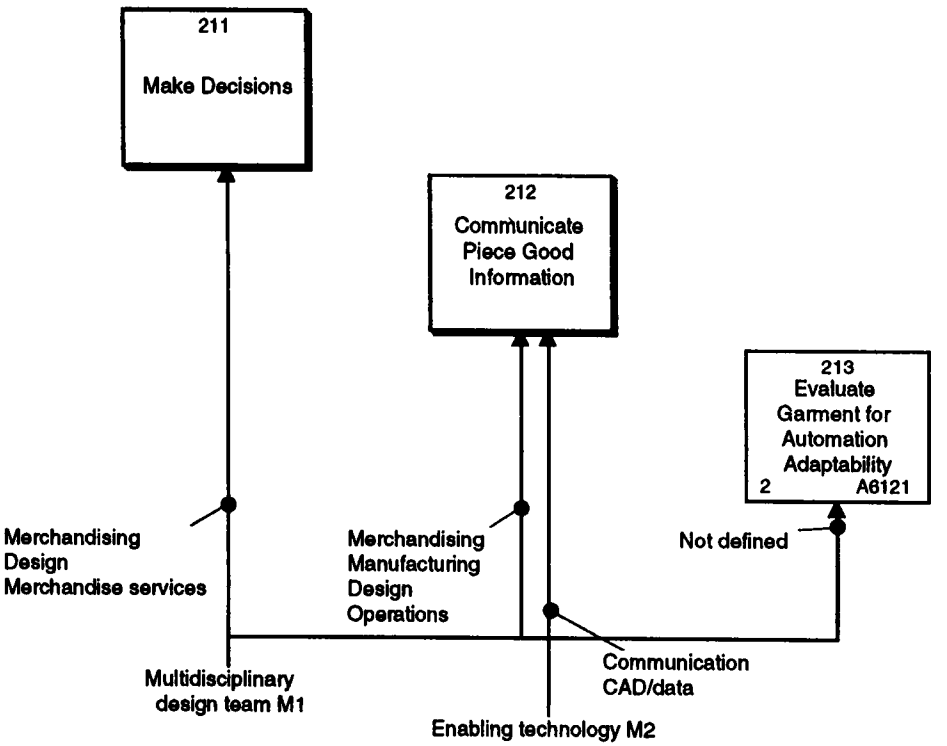
NODE: A16

Figure 141. Maximize average part level.



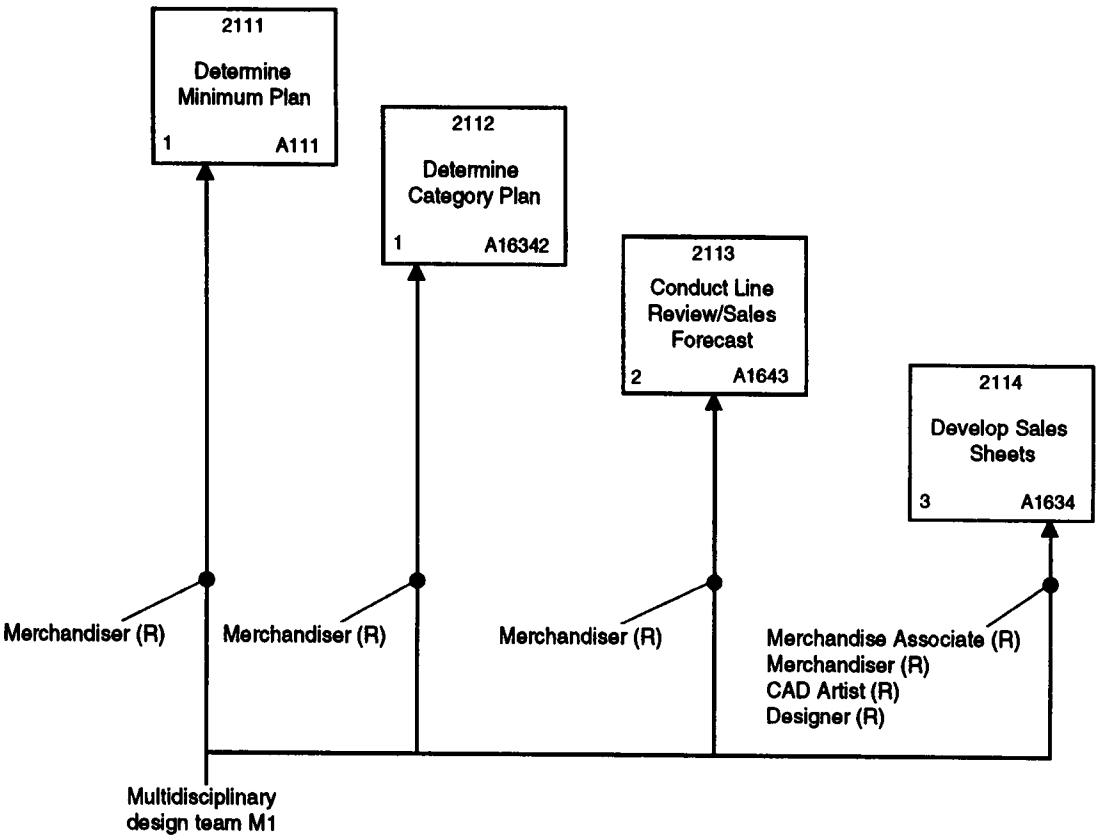
NODE: A2

Figure 142. Design for enabling technology.



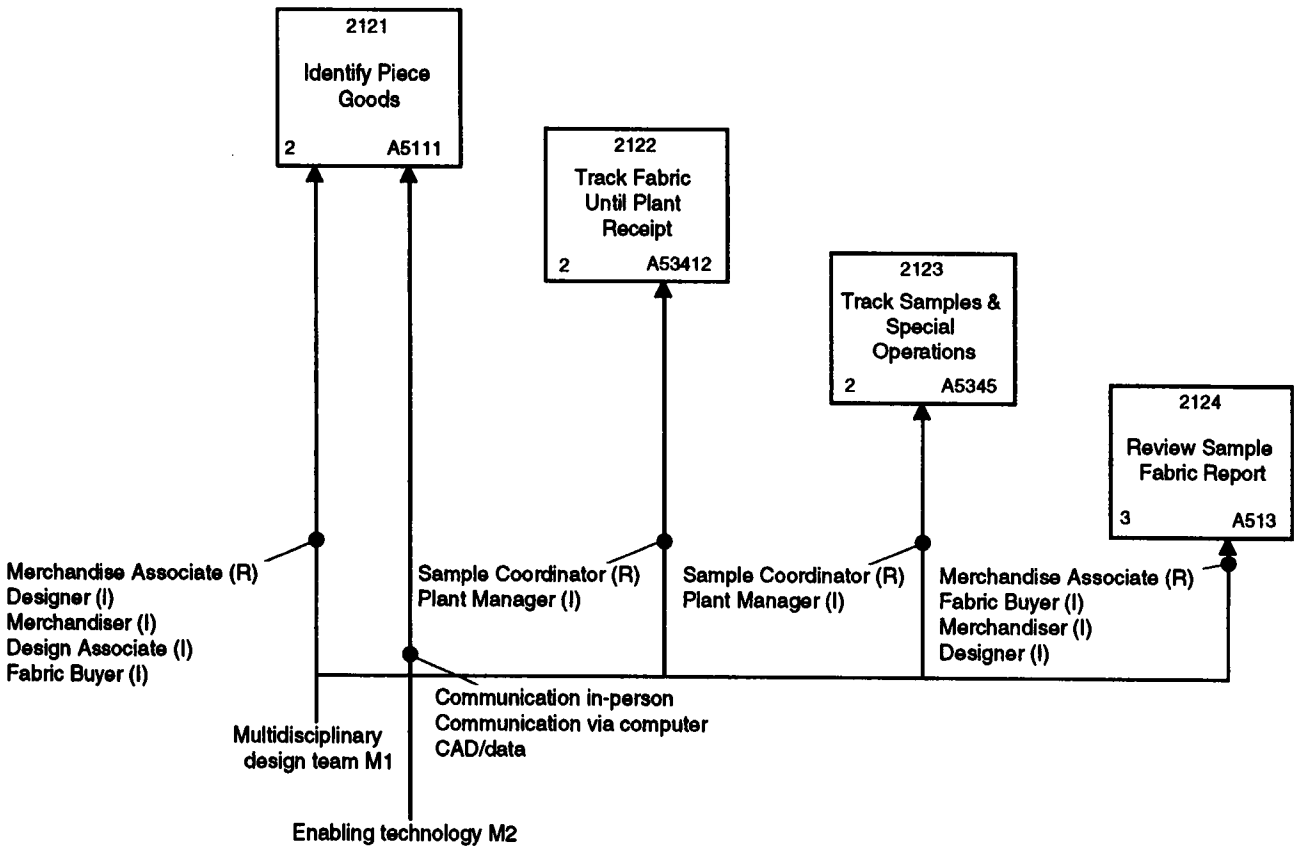
NODE: A21

Figure 143. Optimize design information, use digital product model.



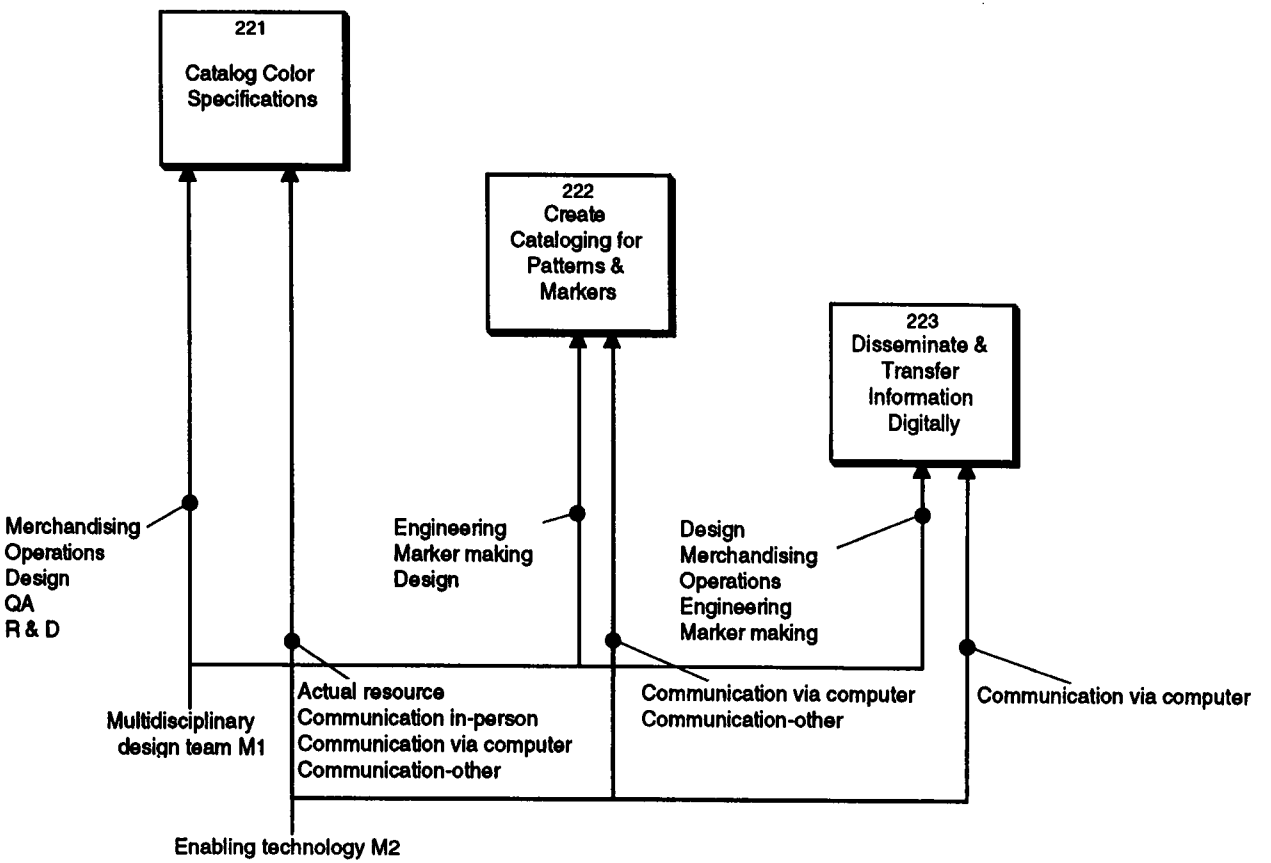
NODE: A211

Figure 144. Make decisions.



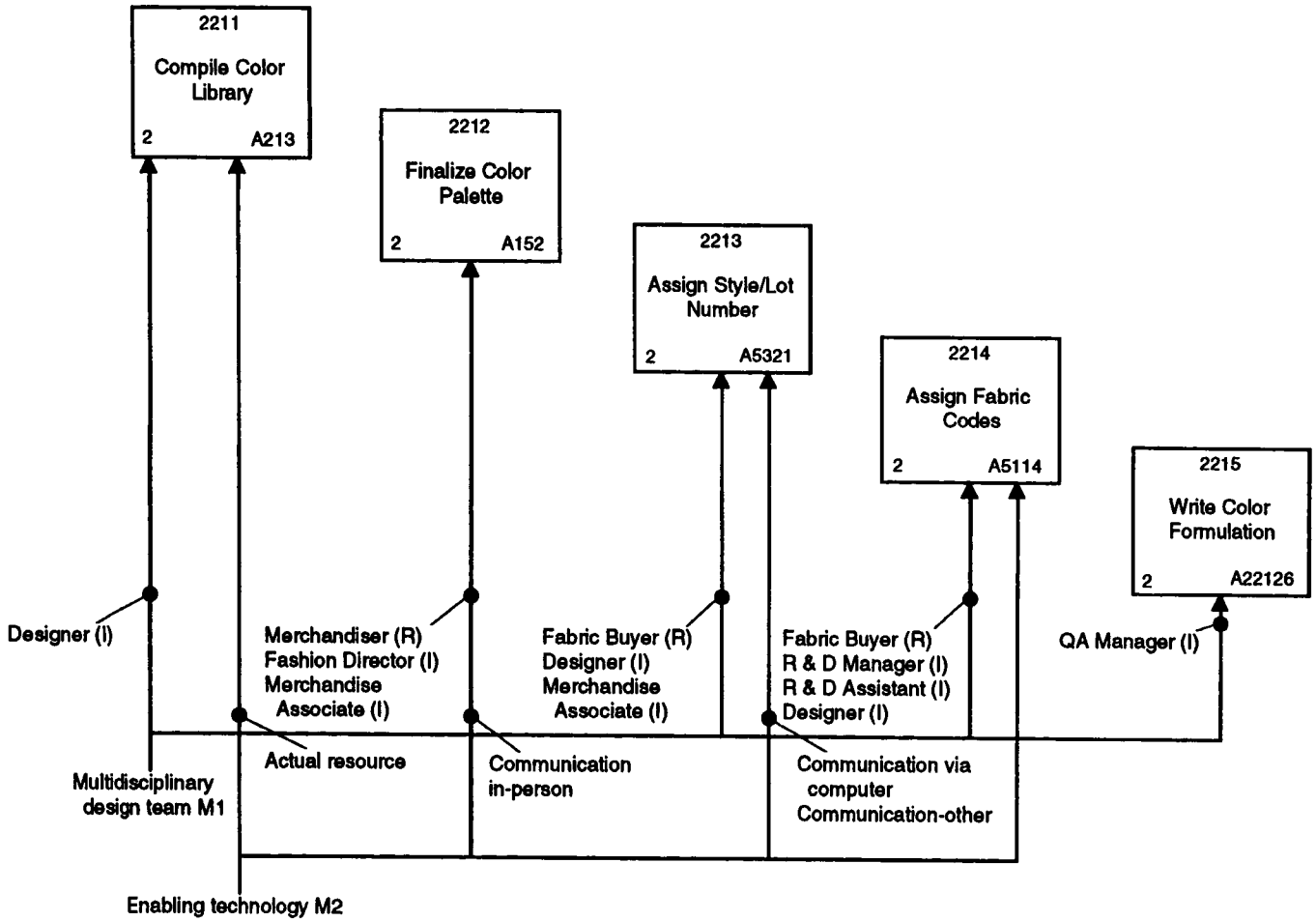
NODE: A212

Figure 145. Communicate piece good information.



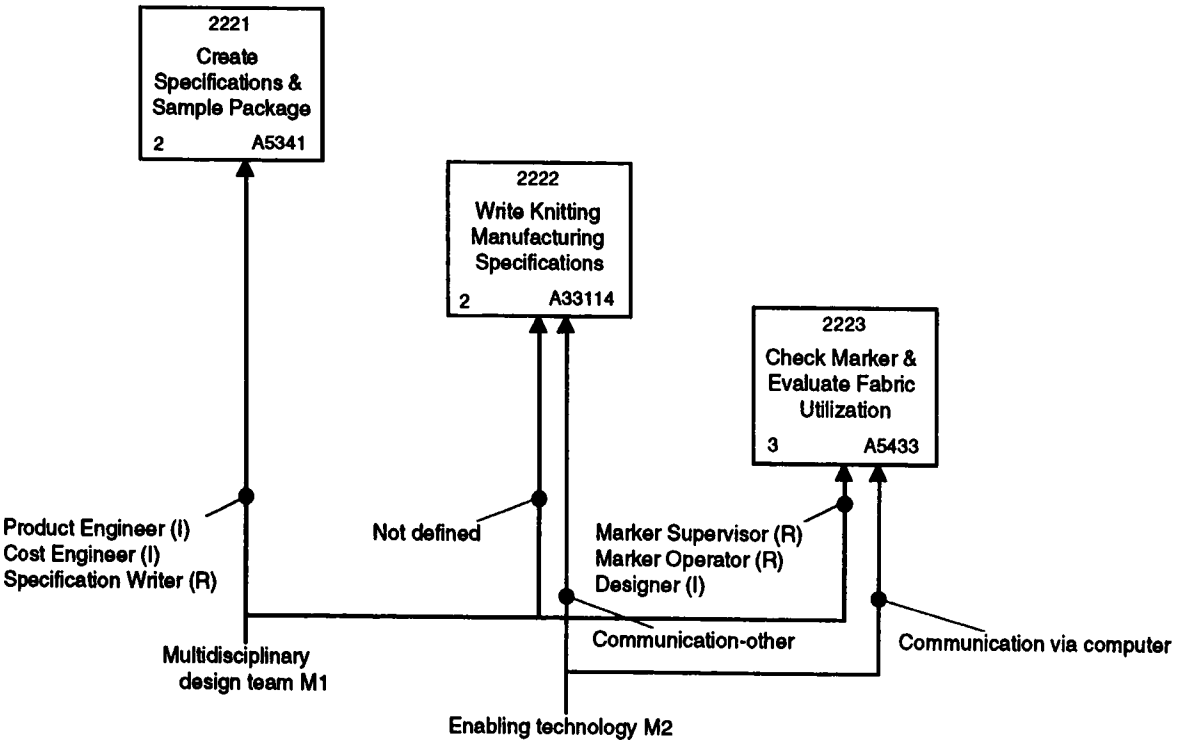
NODE: A22

Figure 146. Store information in consistent, non-redundant manner.



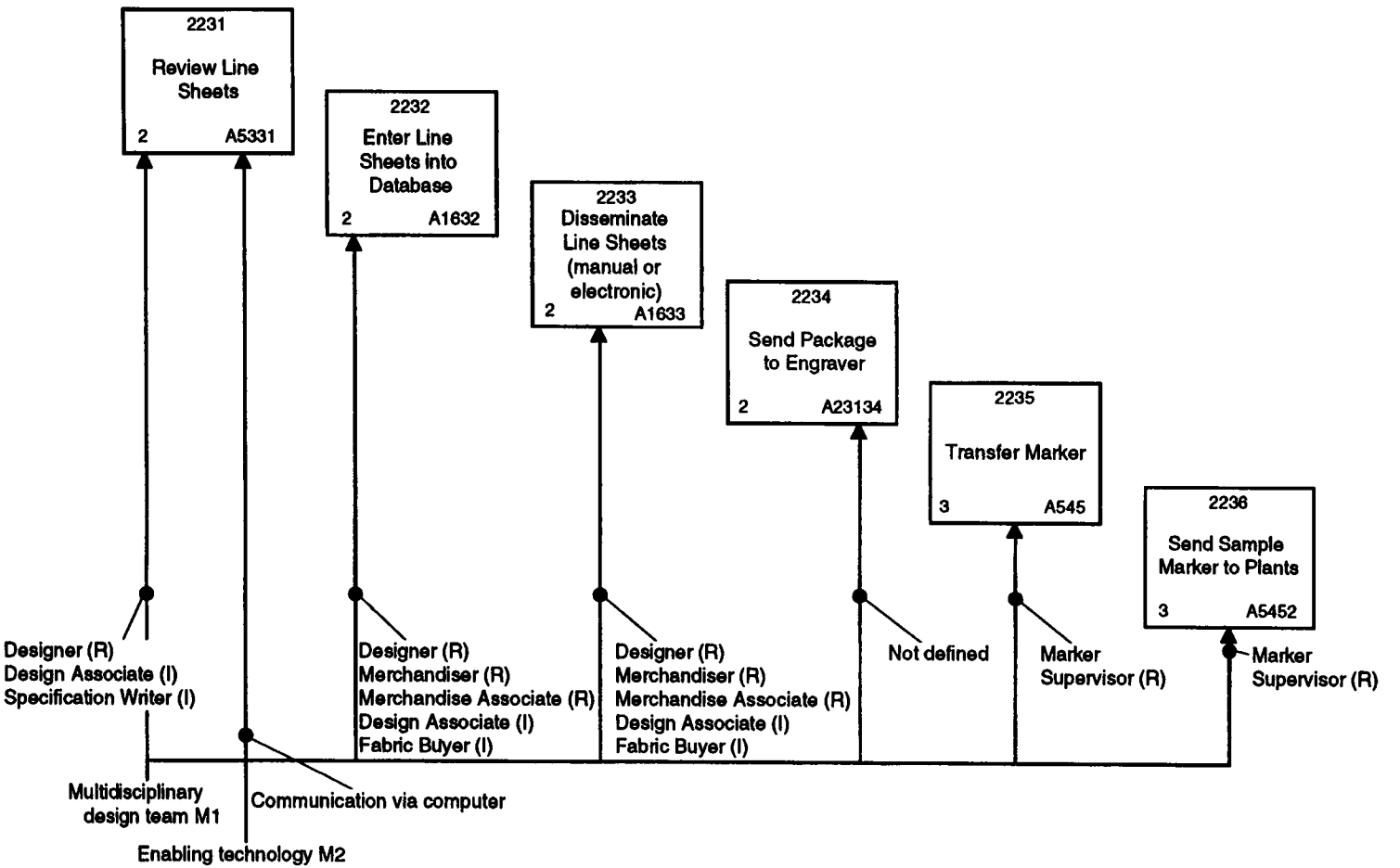
NODE: A221

Figure 147. Catalog color specifications.



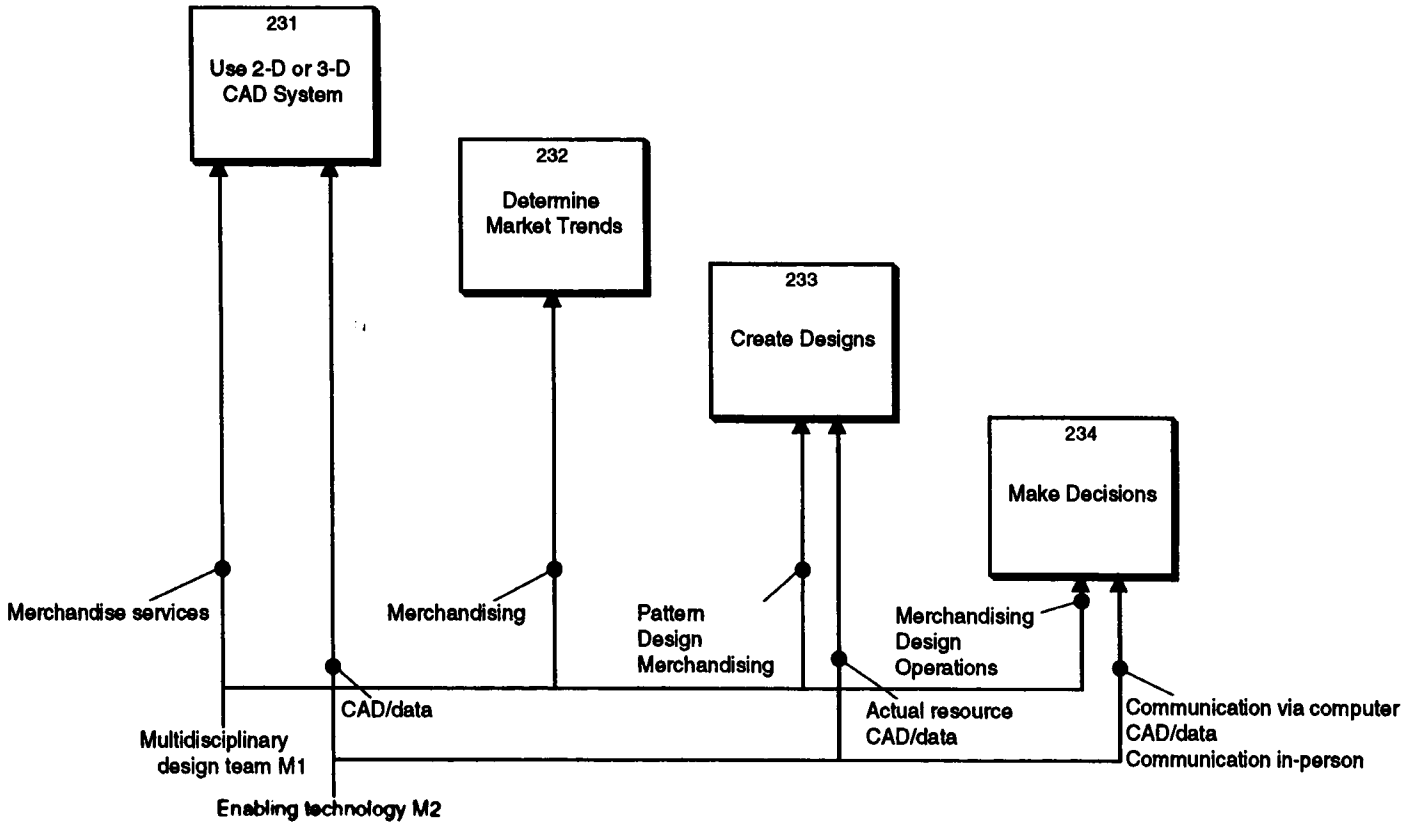
NODE: A222

Figure 148. Create cataloging for patterns & markers.



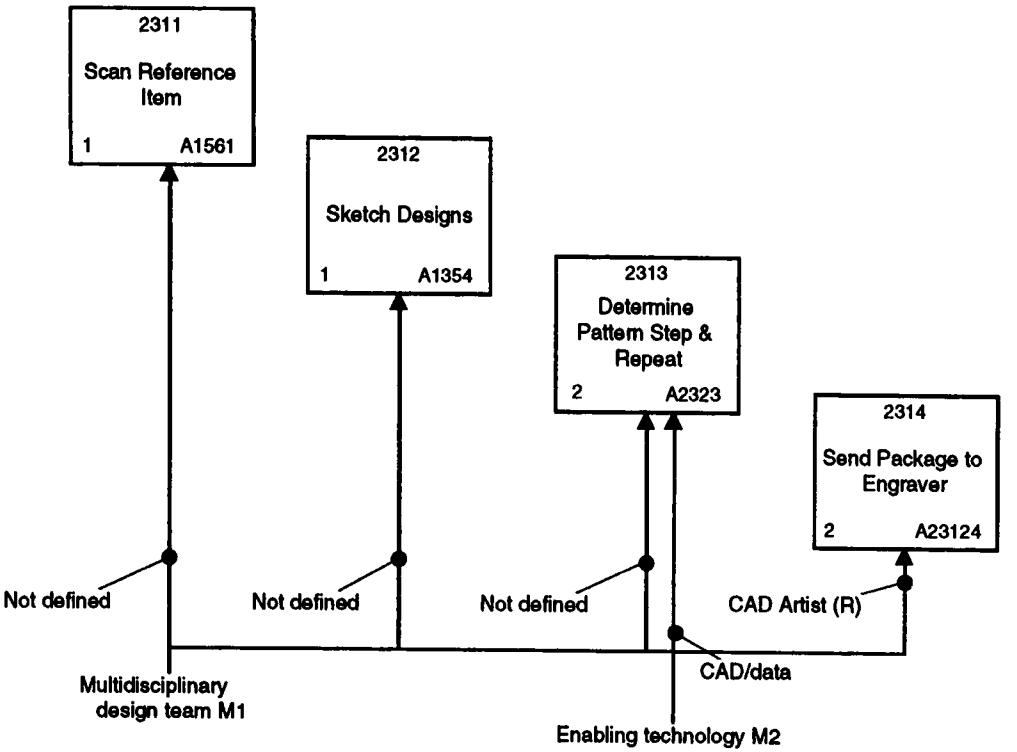
NODE: A223

Figure 149. Disseminate & transfer information digitally.



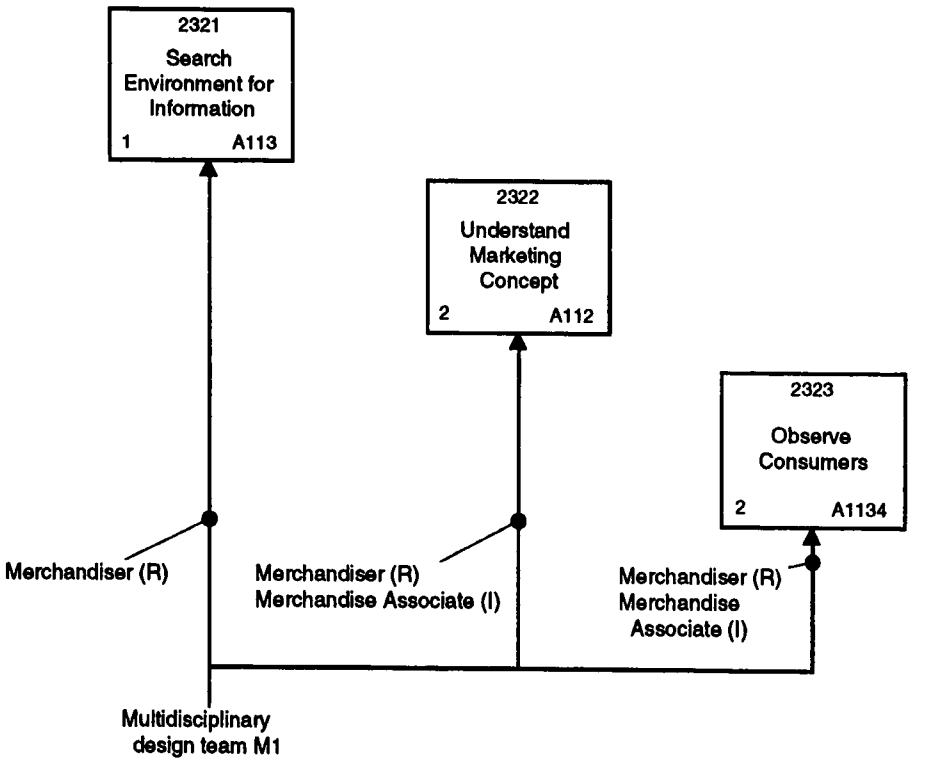
NODE: A23

Figure 150. Use accumulated design information.



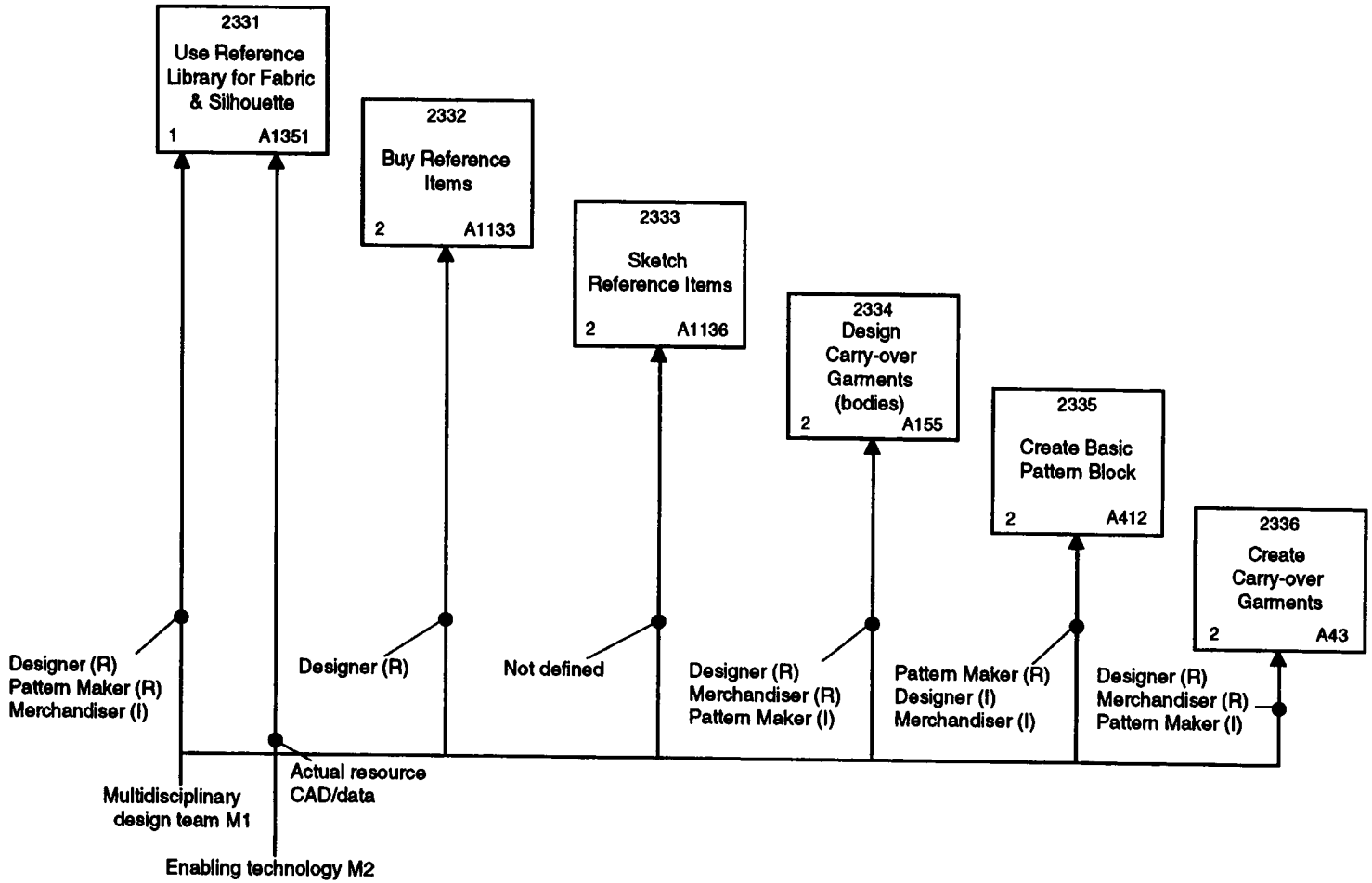
NODE: A231

Figure 151. Use 2-D or 3-D CAD system.



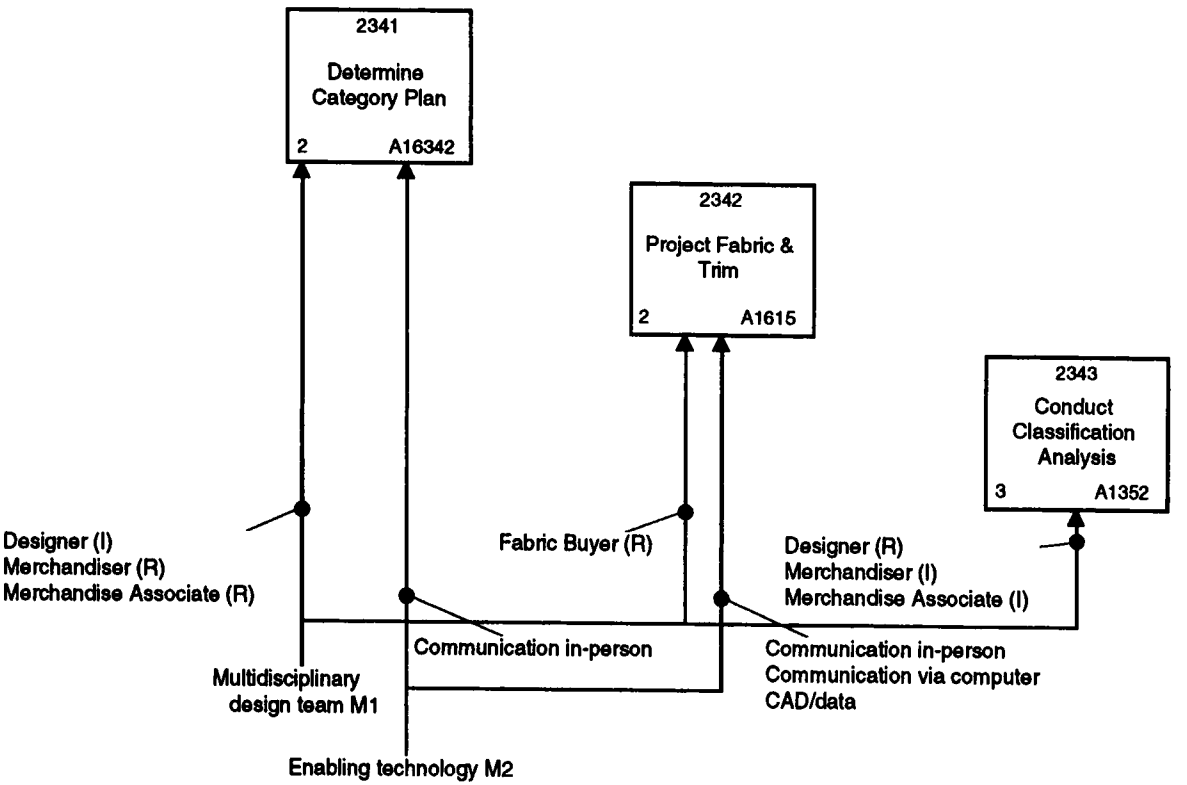
NODE: A232

Figure 152. Determine market trends.



NODE: A233

Figure 153. Create designs.



NODE: A234

Figure 154. Make decisions.

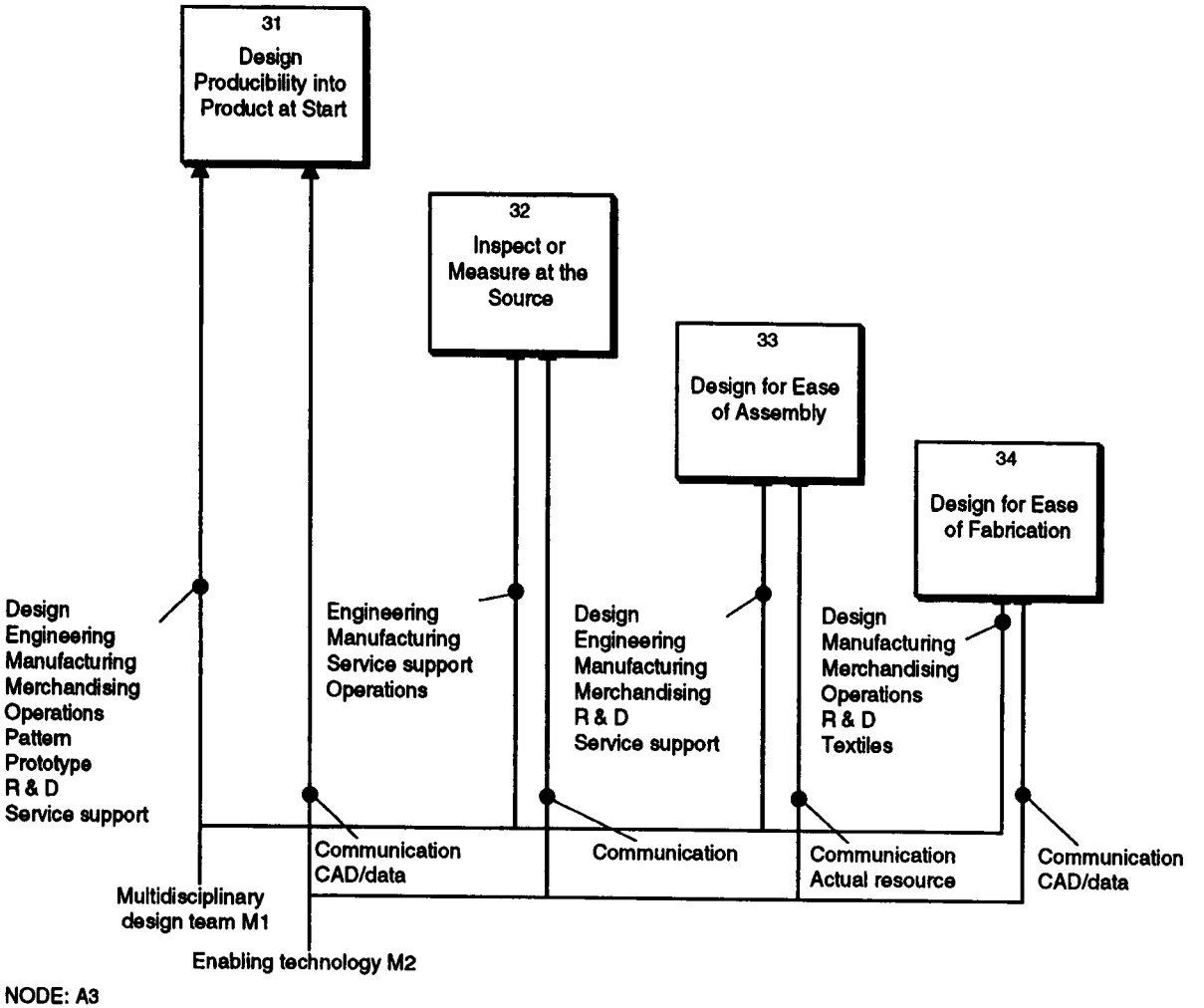


Figure 155. Design for manufacturability.

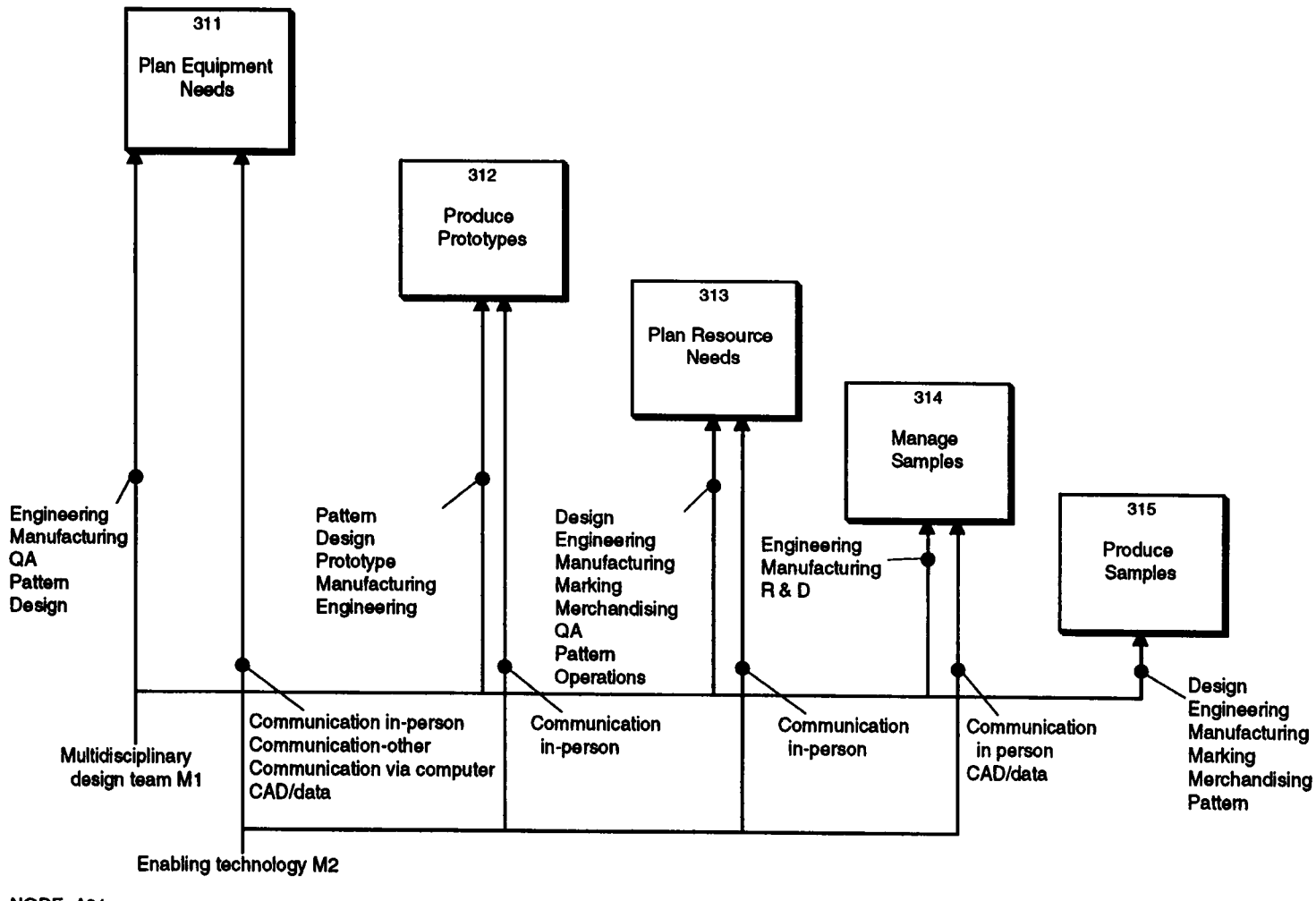


Figure 156. Design producibility into product at start.

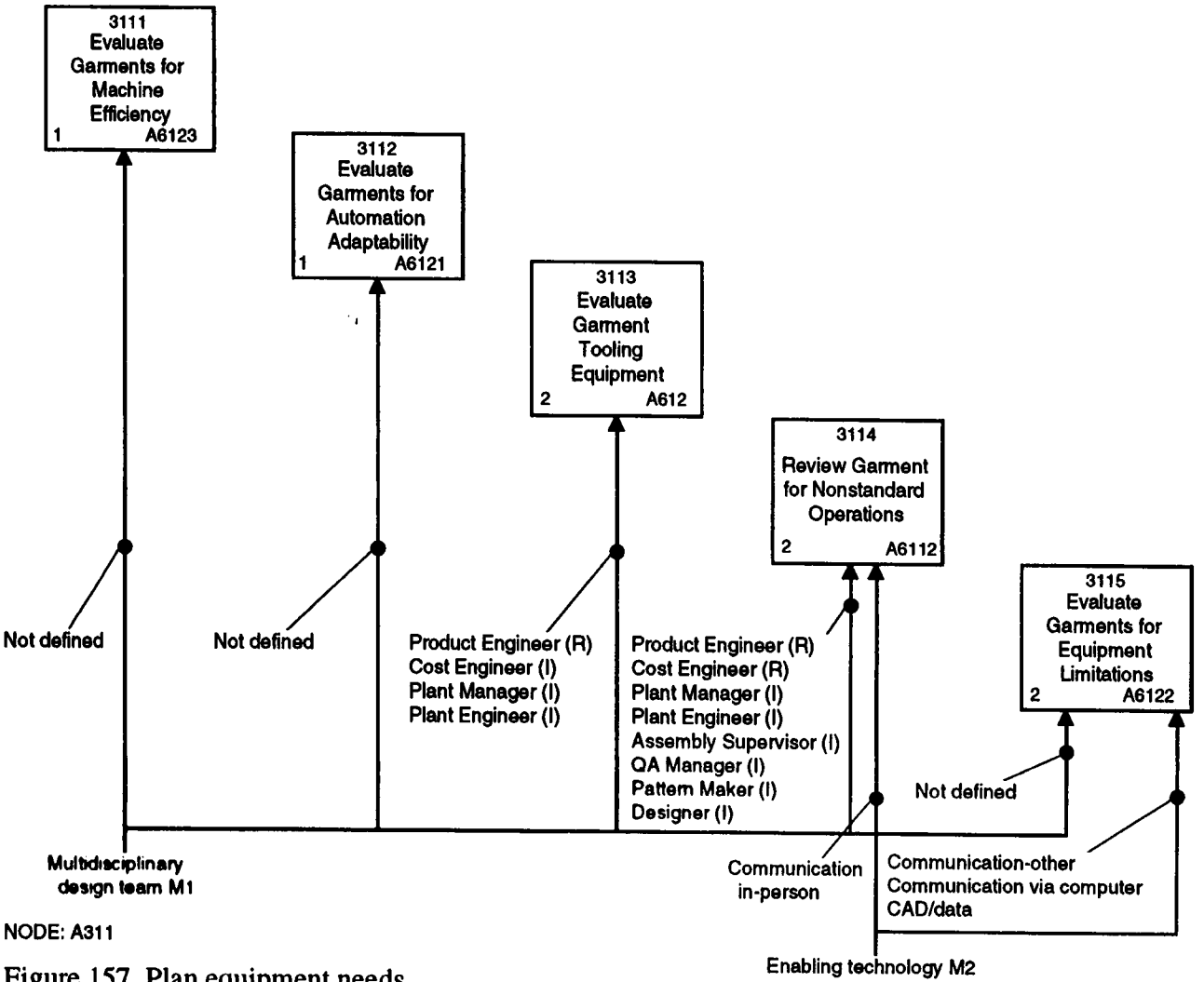
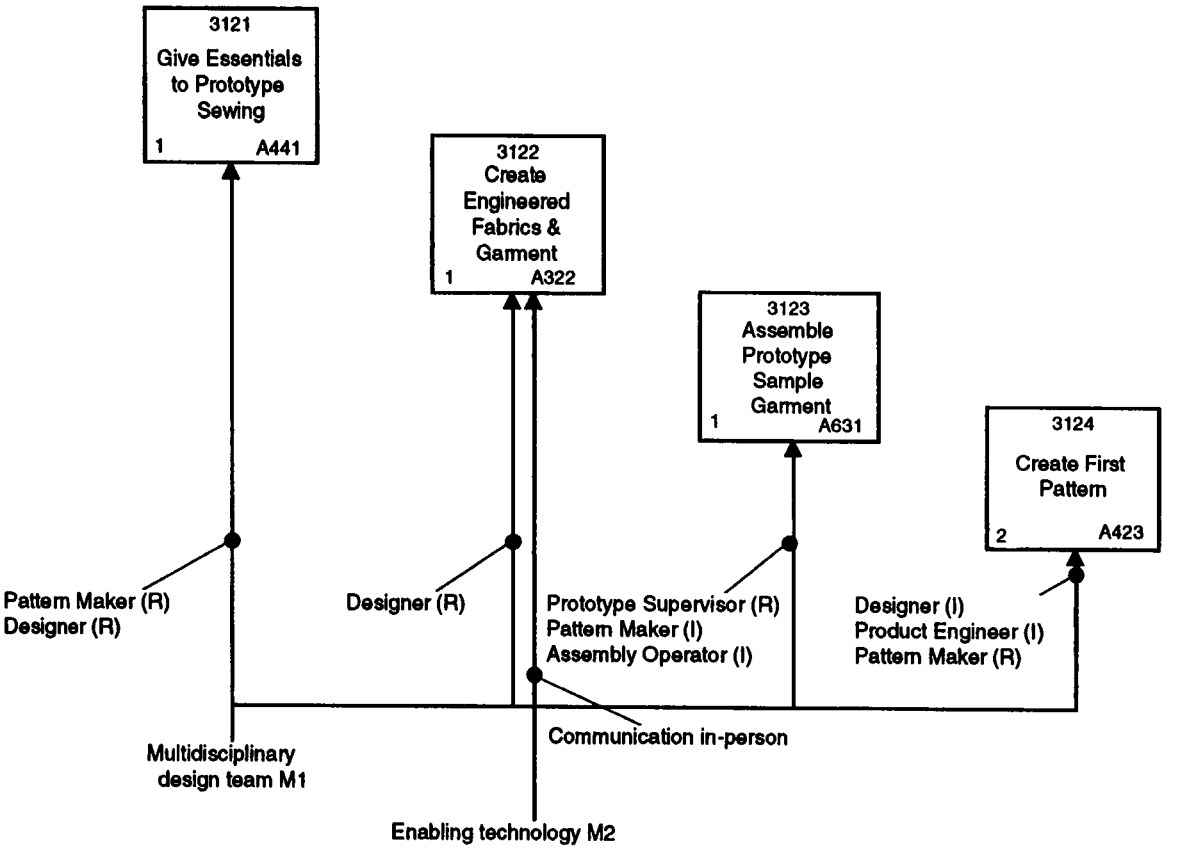
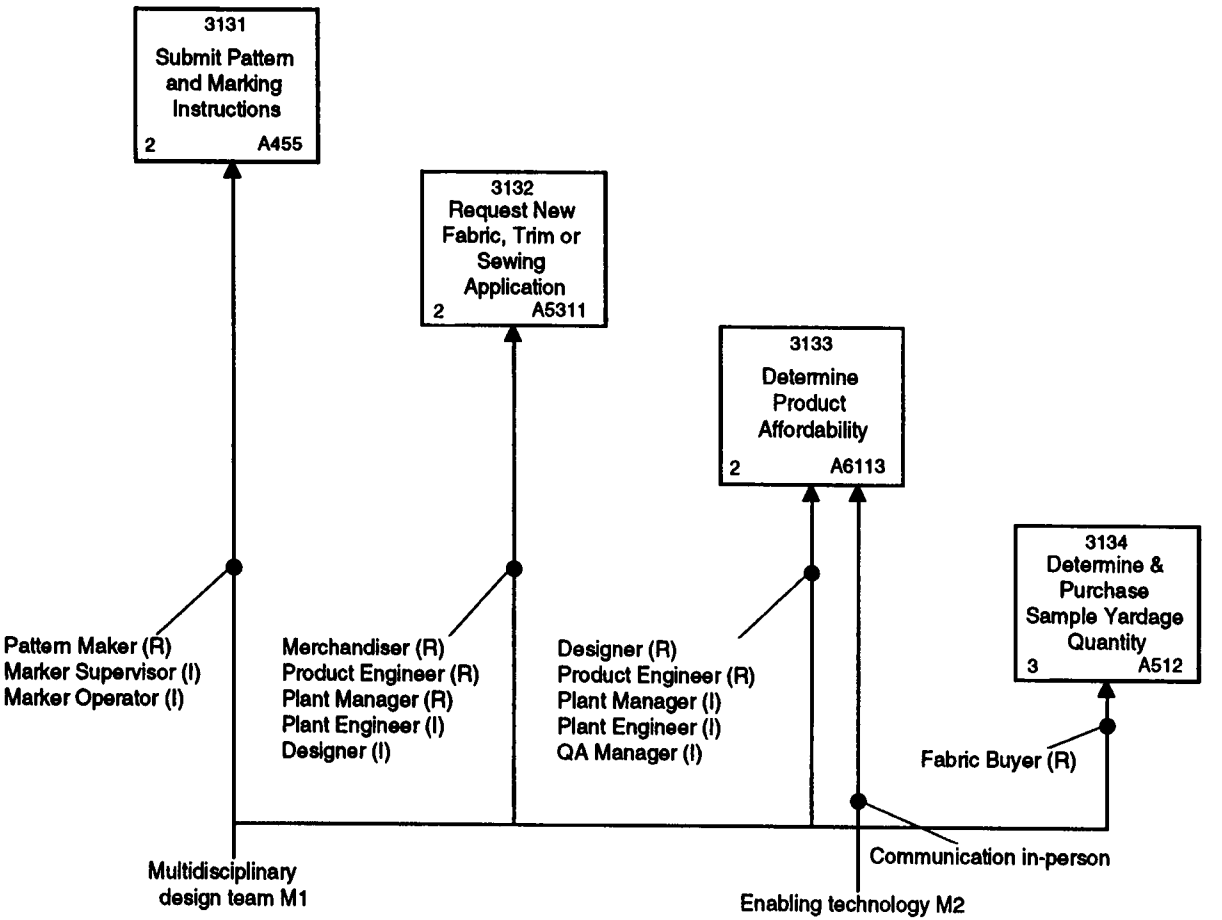


Figure 157. Plan equipment needs.



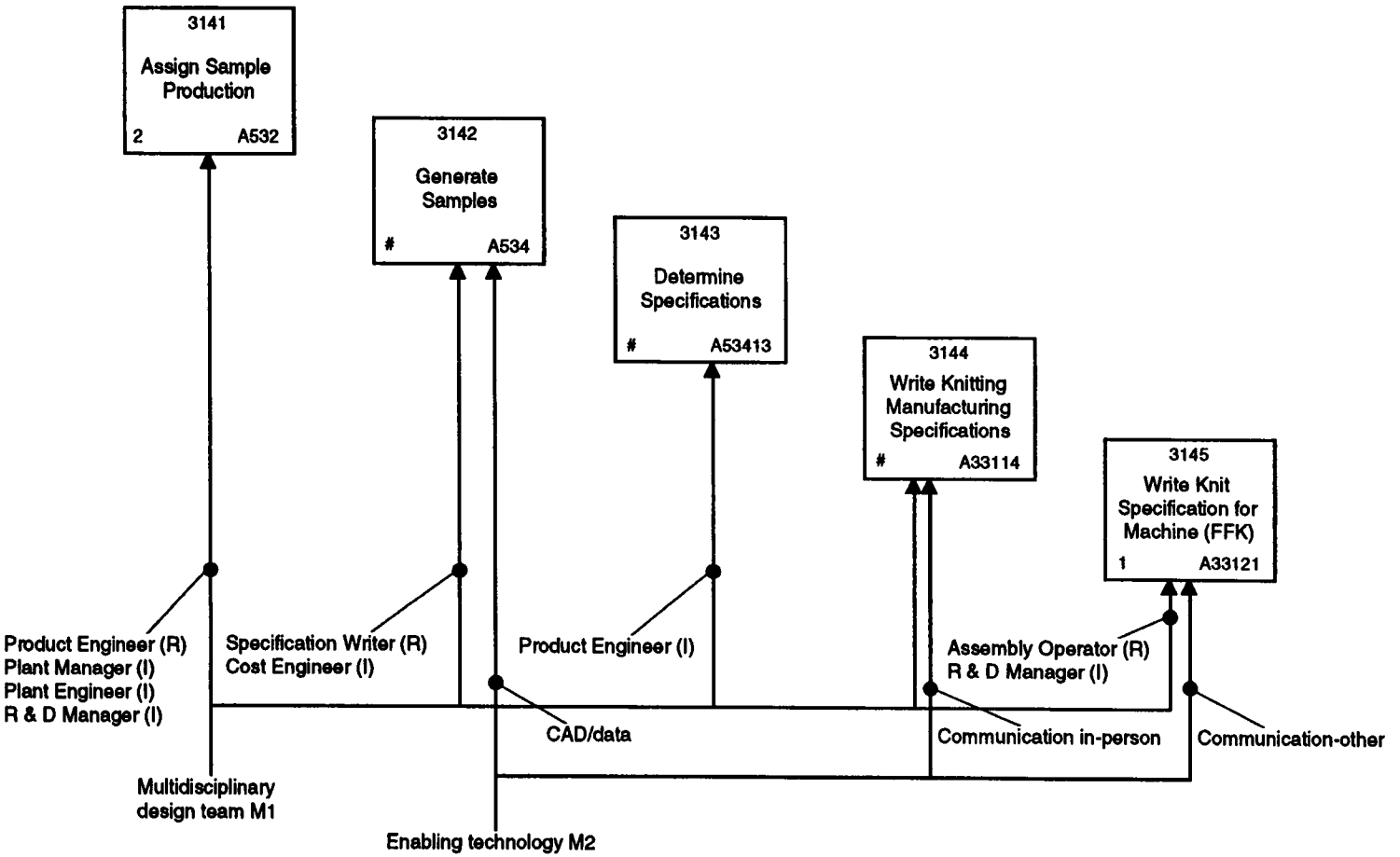
NODE: A312

Figure 158. Produce prototypes.



NODE: A313

Figure 159. Plan resource needs.



NODE: A314

Figure 160. Manage samples.

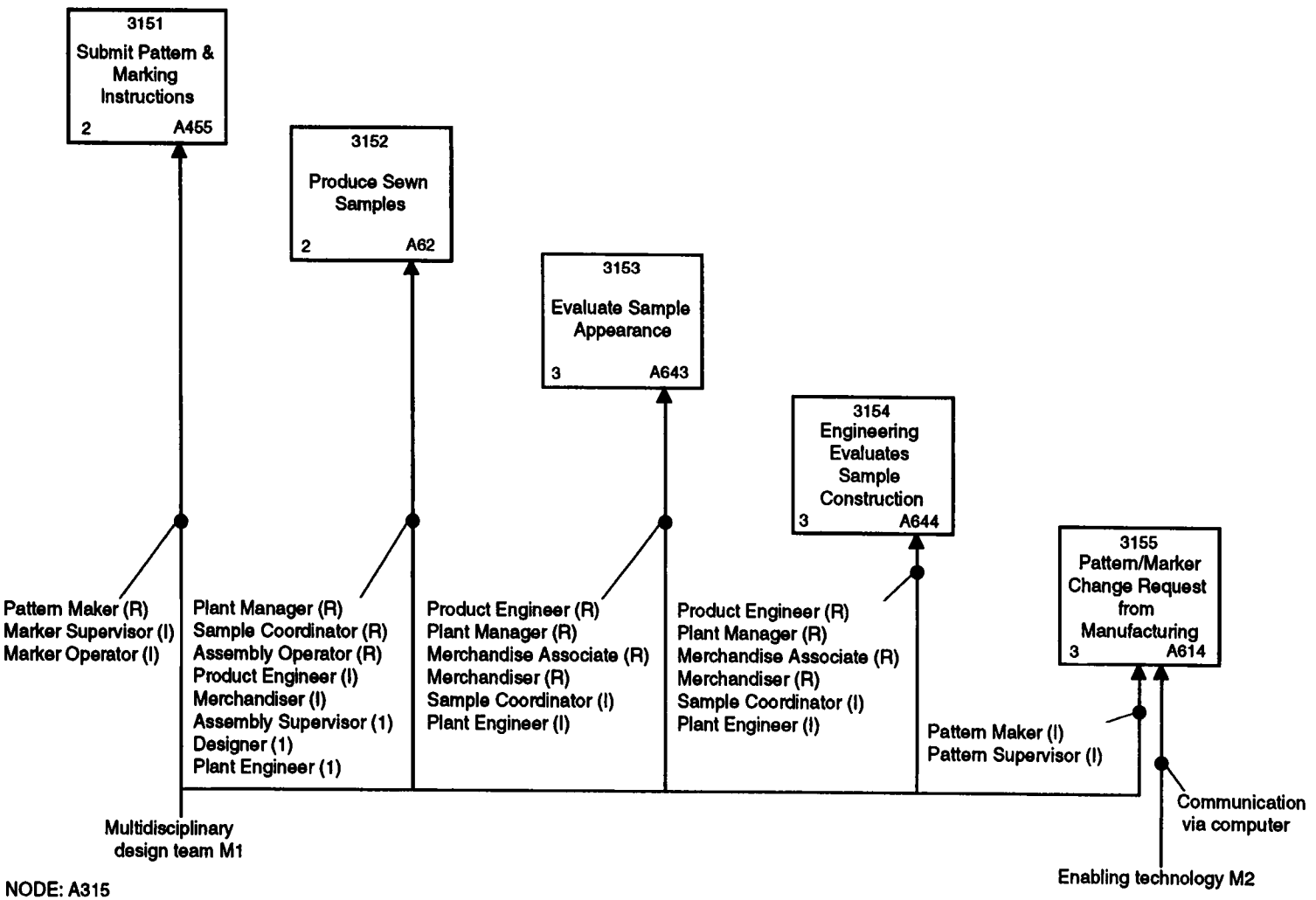


Figure 161. Produce samples.

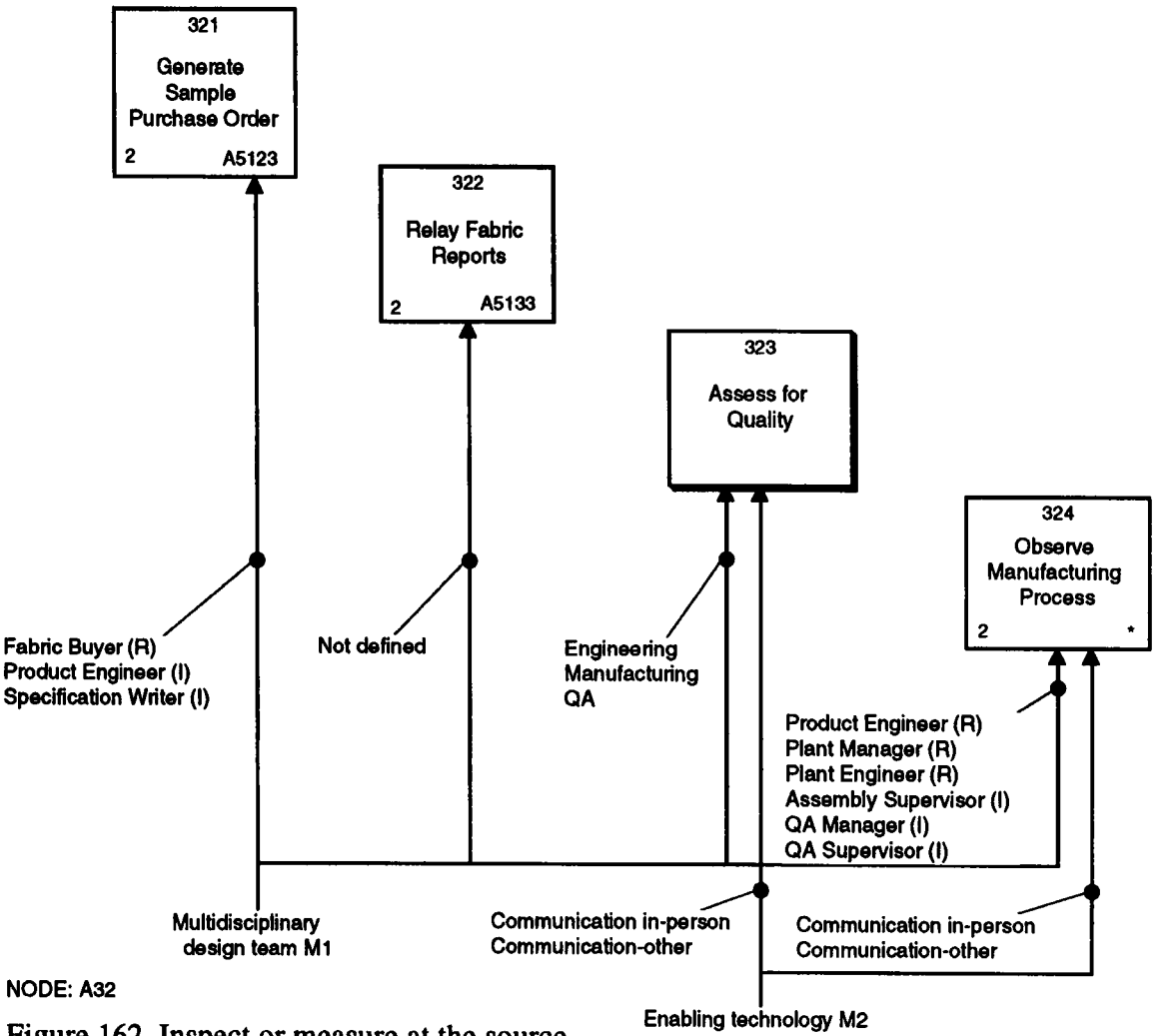
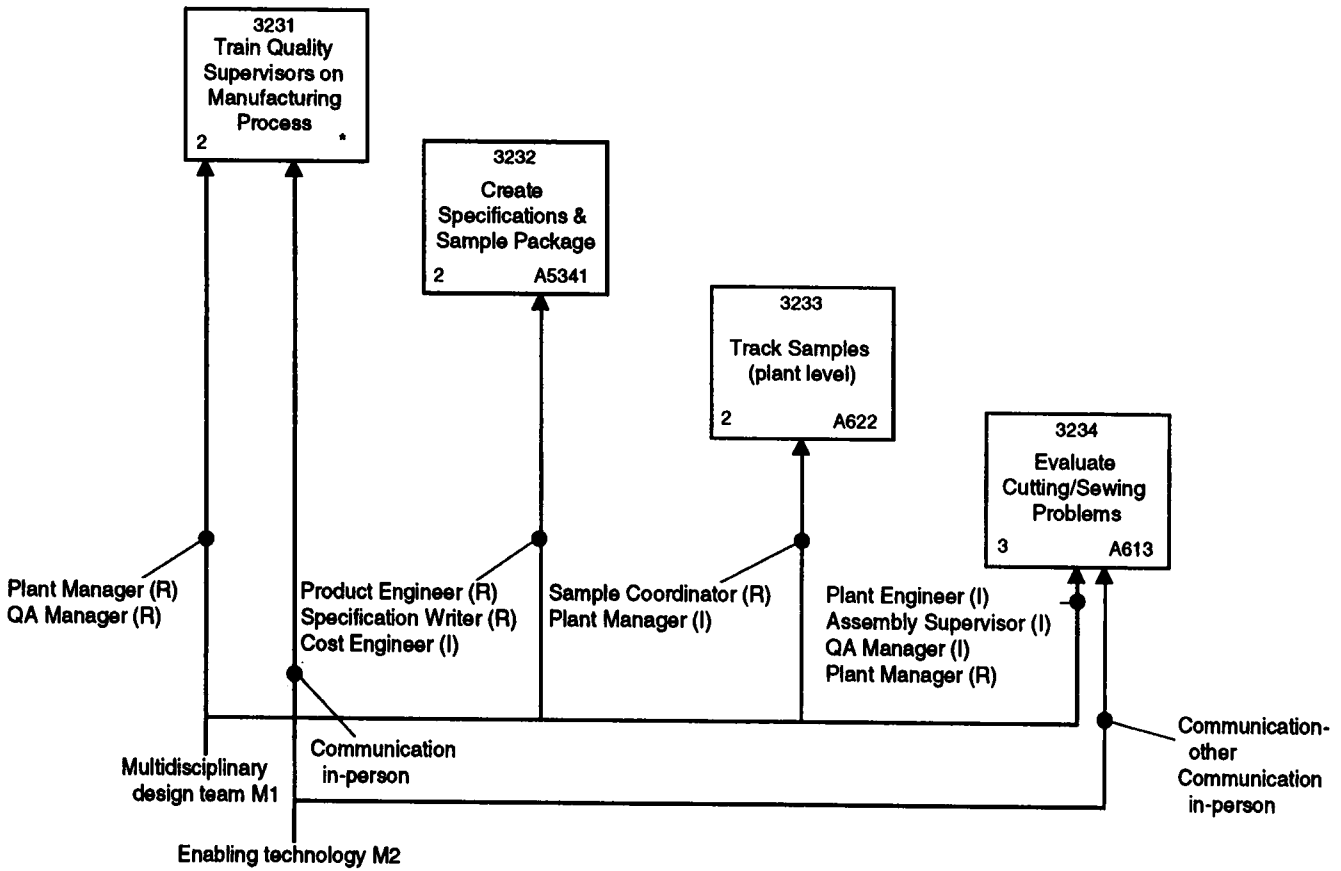


Figure 162. Inspect or measure at the source.



NODE: A323

Figure 163. Assess for quality.

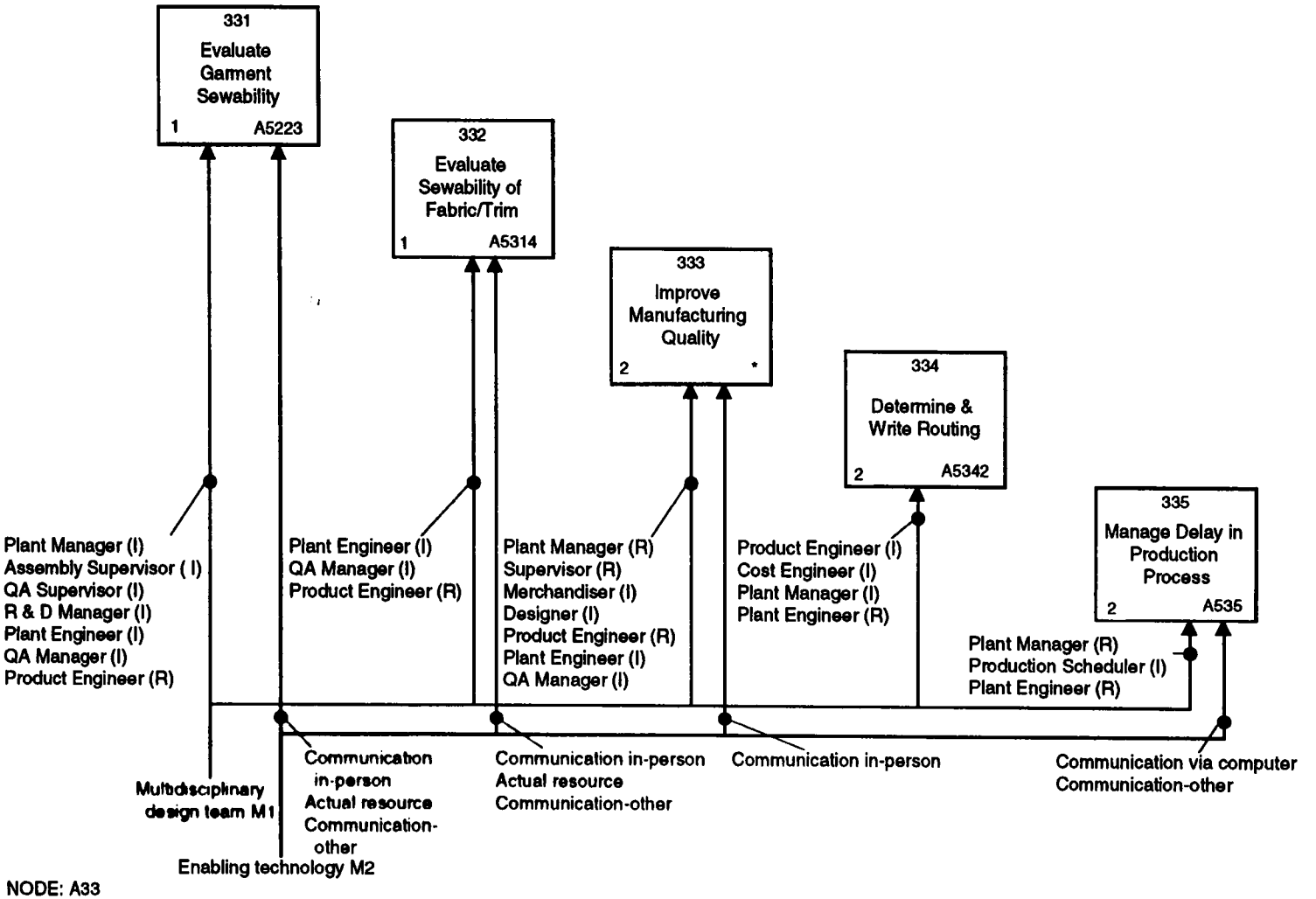
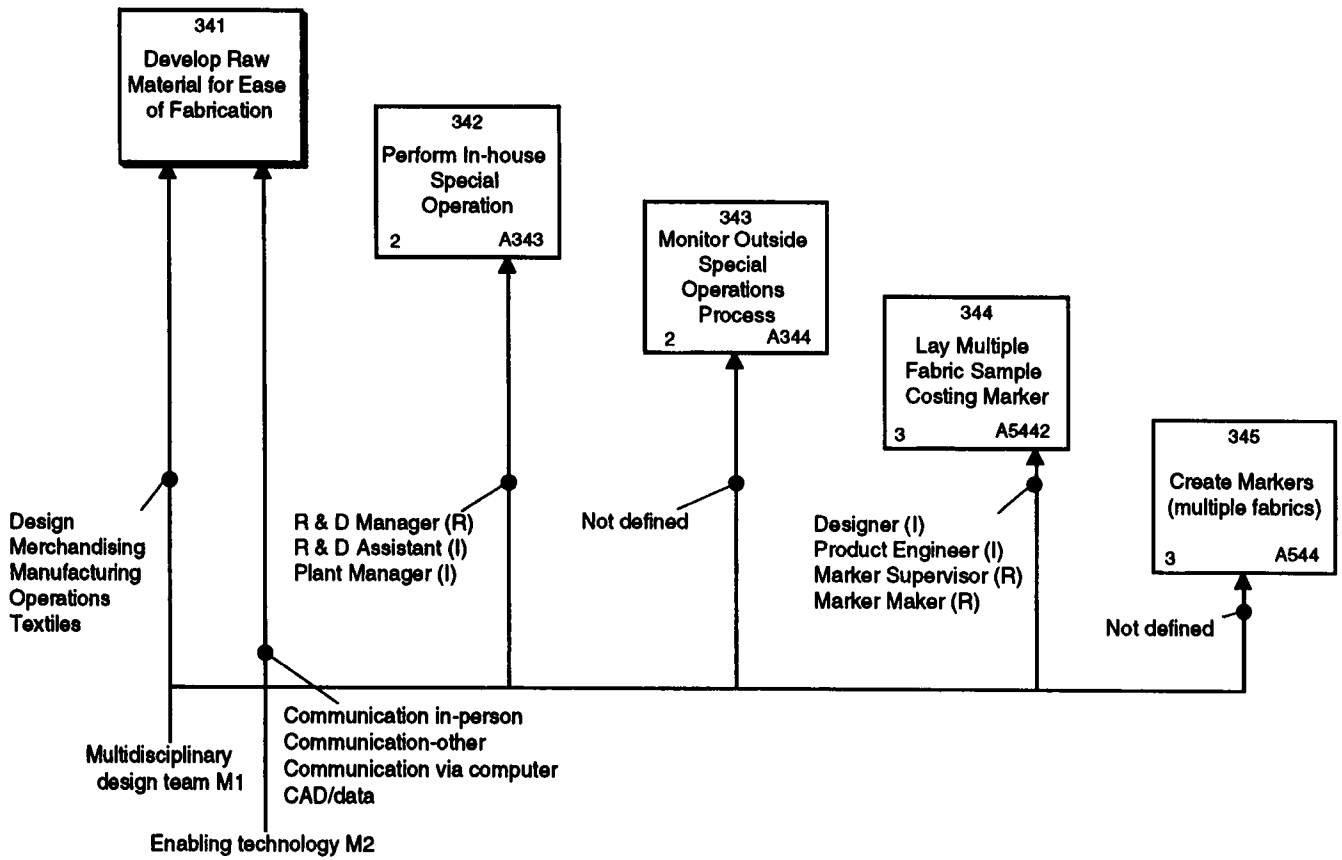
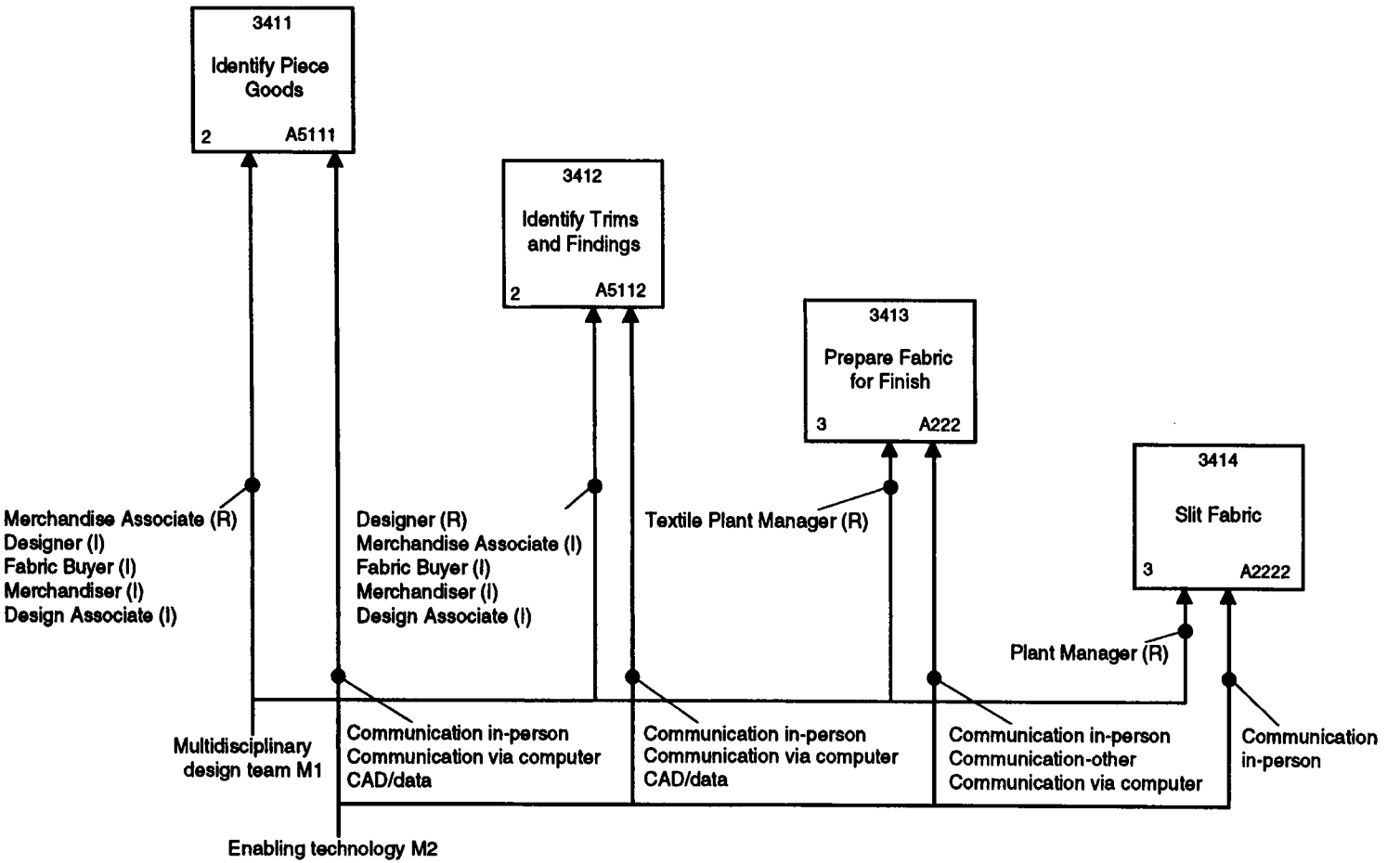


Figure 164. Design for ease of assembly.



NODE: A34

Figure 165. Design for ease of fabrication.



NODE: A341

Figure 166. Develop raw material for ease of fabrication.

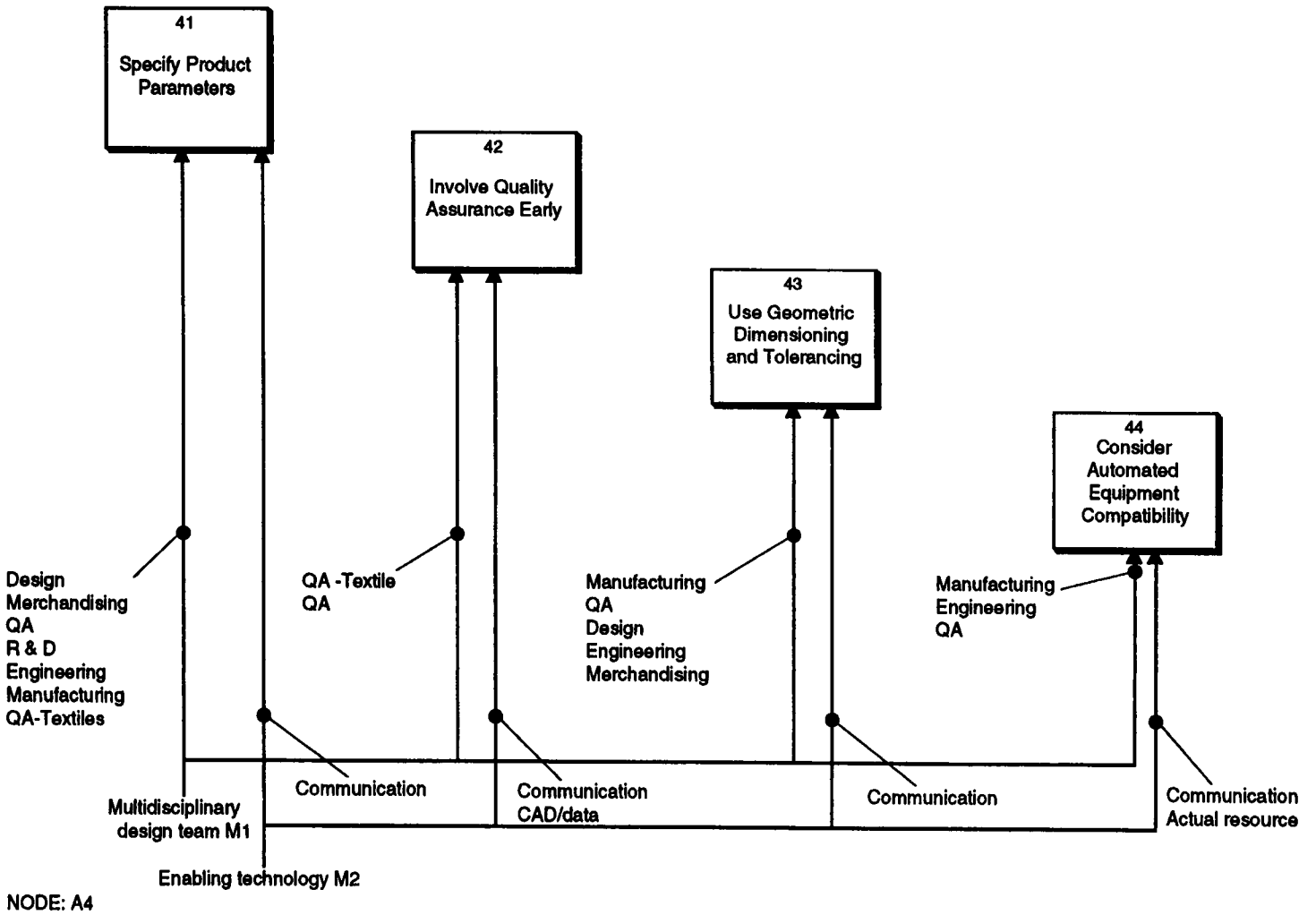
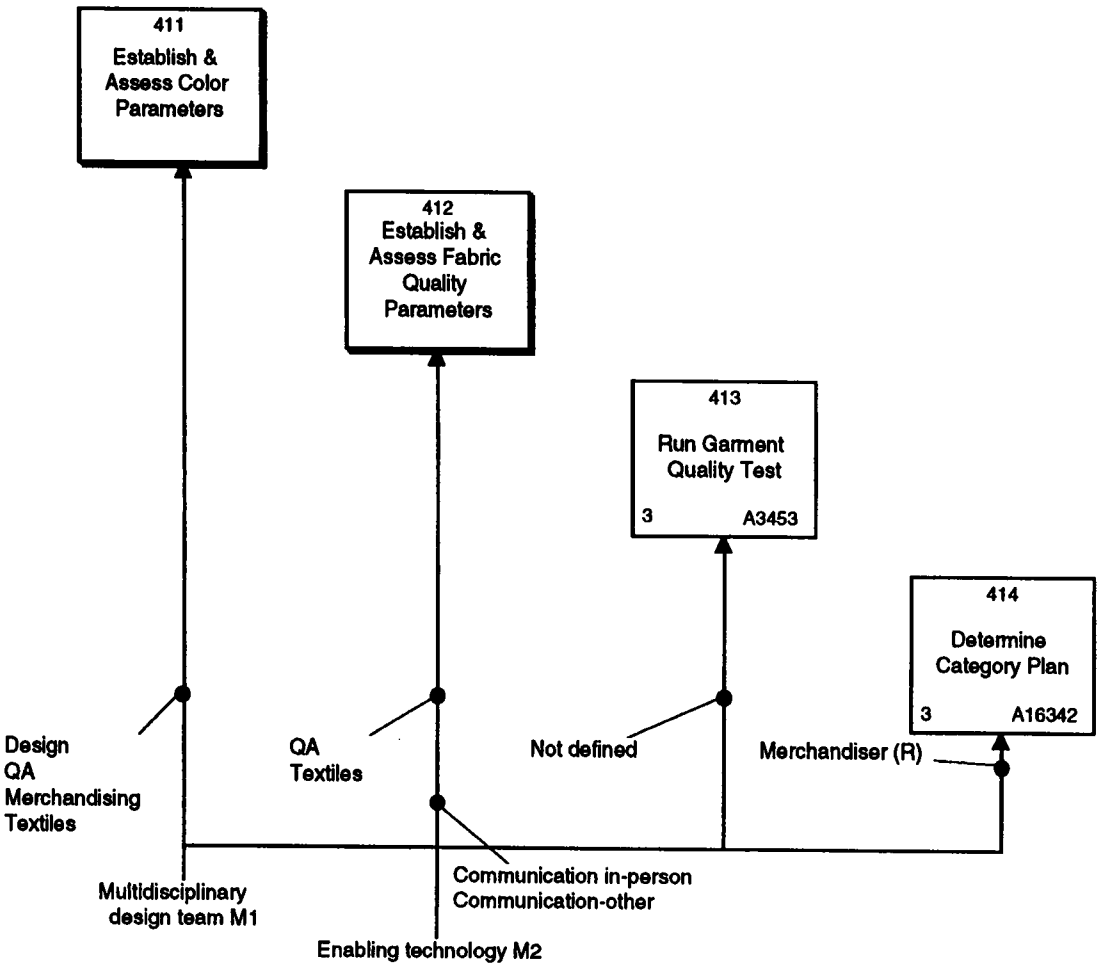
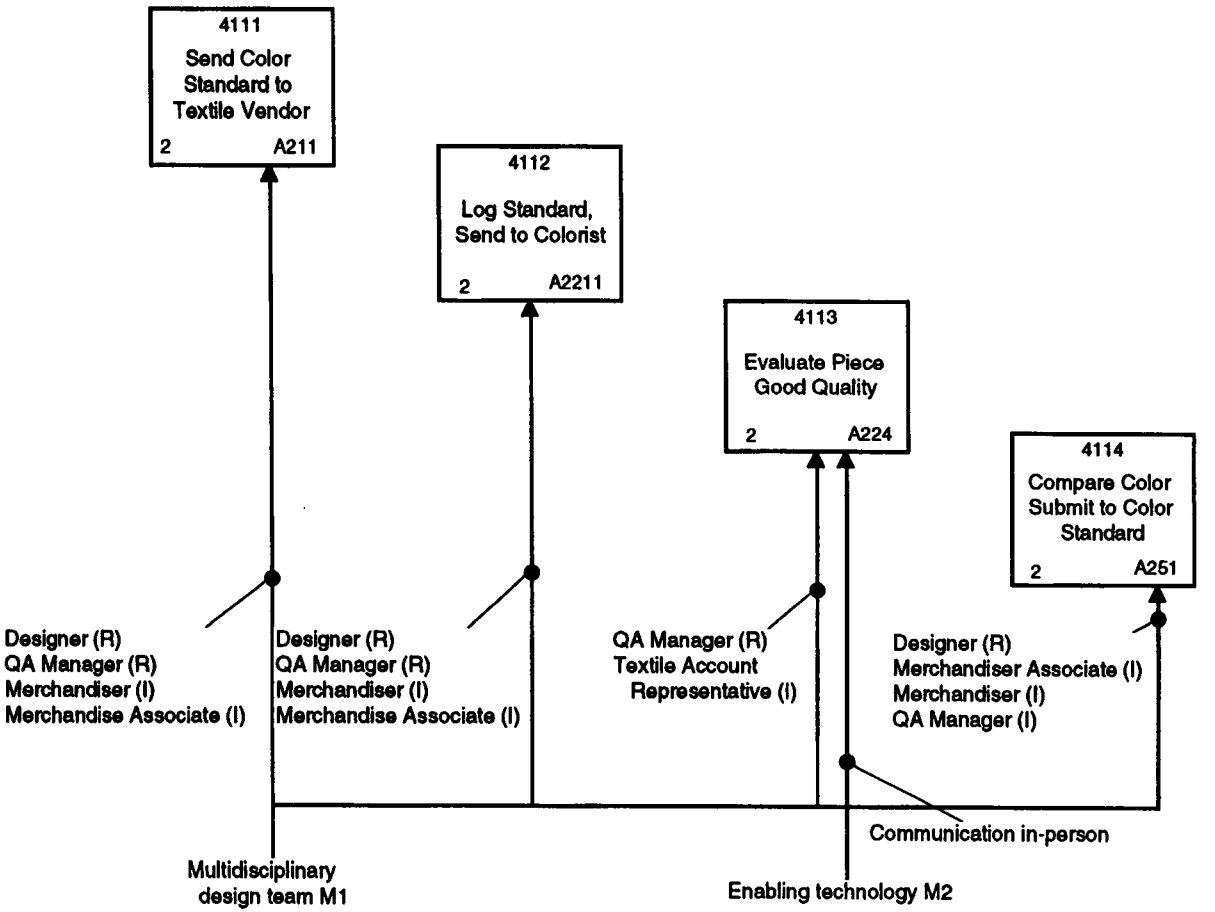


Figure 167. Design for life cycle inspectability.



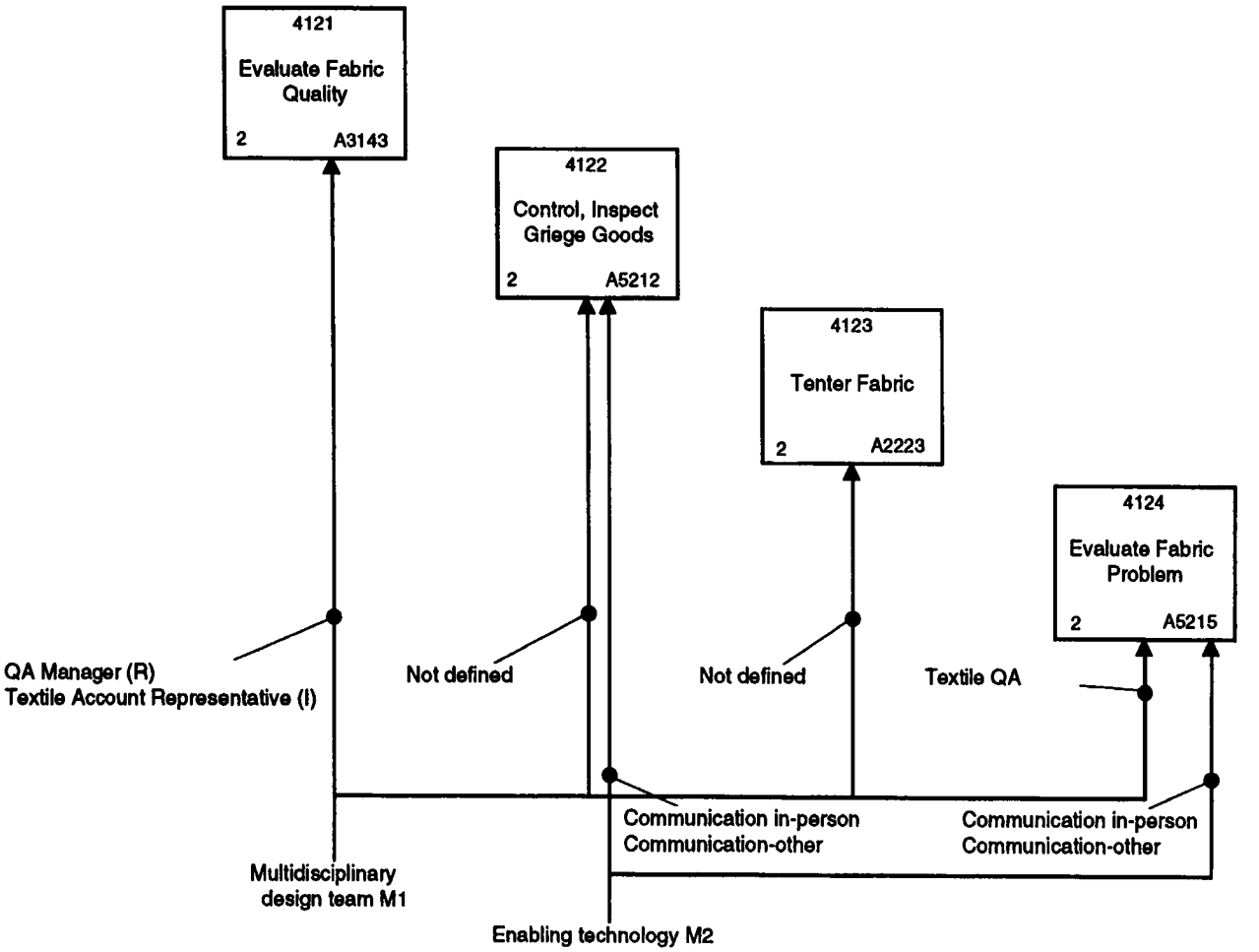
NODE: A41

Figure 168. Specify product parameters.



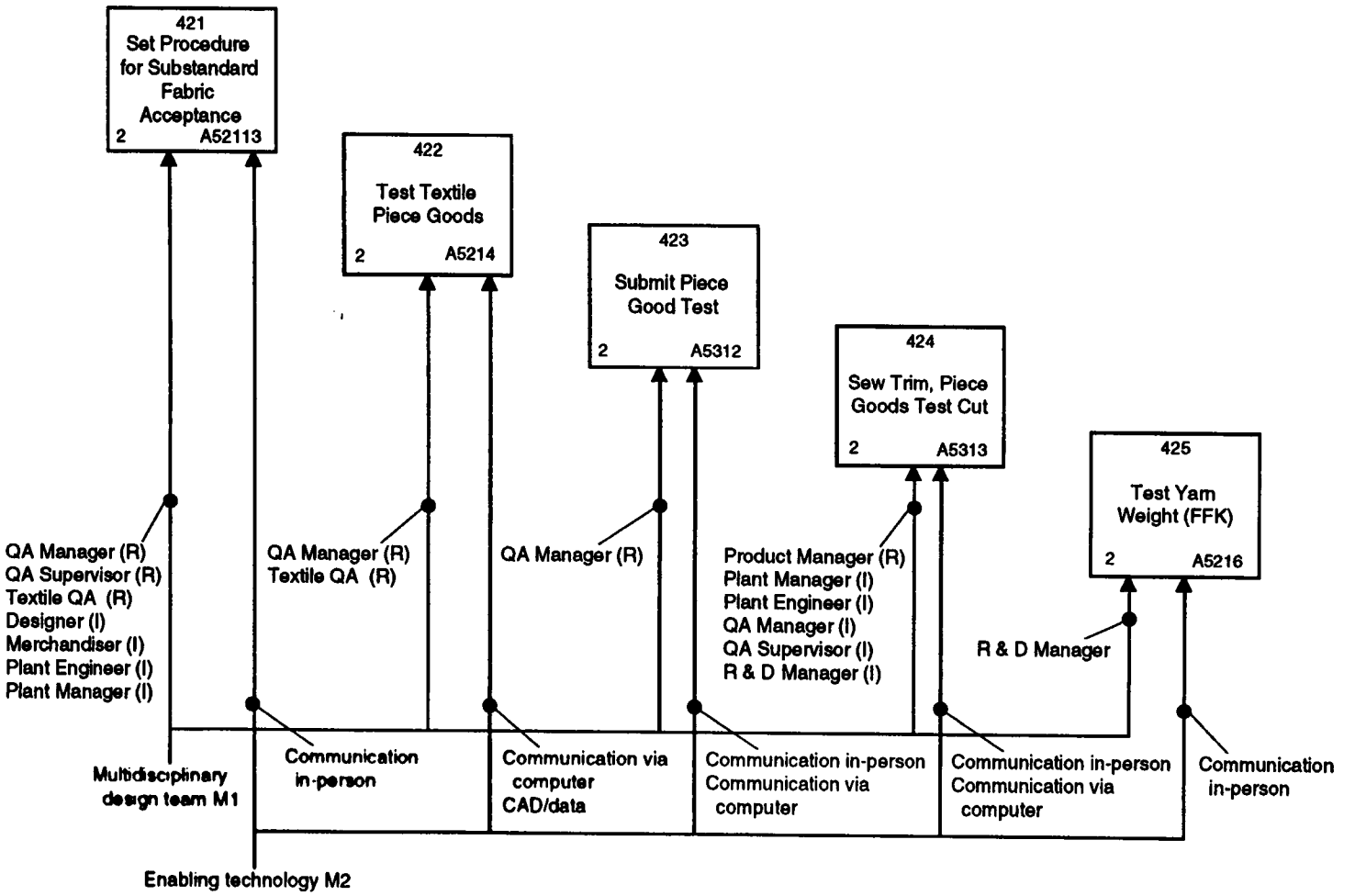
NODE: A411

Figure 169. Establish and assess color parameters.



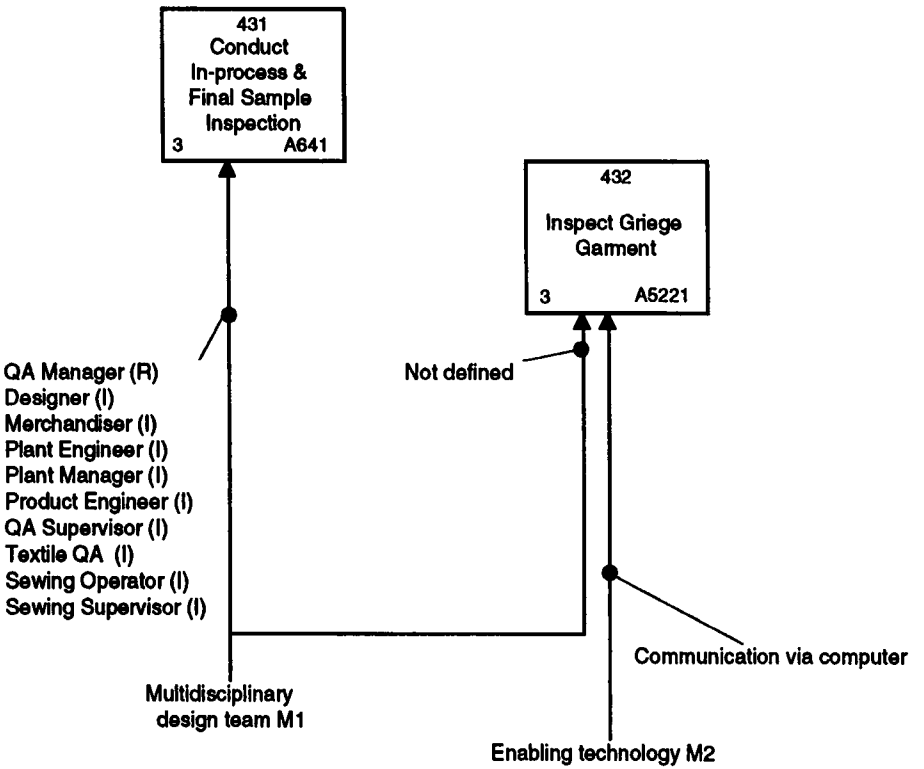
NODE: A412

Figure 170. Establish and assess fabric quality parameters.



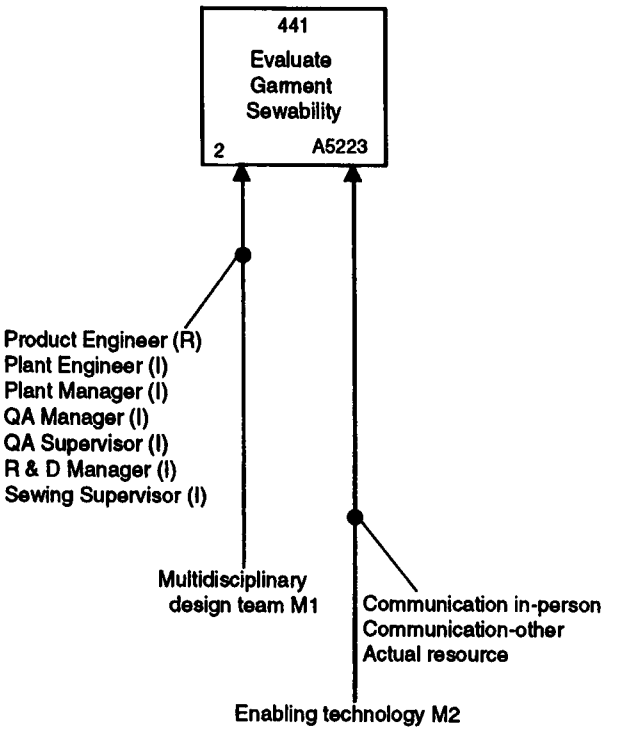
NODE: 42

Figure 171. Involve quality assurance early.



NODE: A43

Figure 172. Use geometric dimensioning and tolerancing.



NODE: A44

Figure 173. Consider automated equipment compatibility.

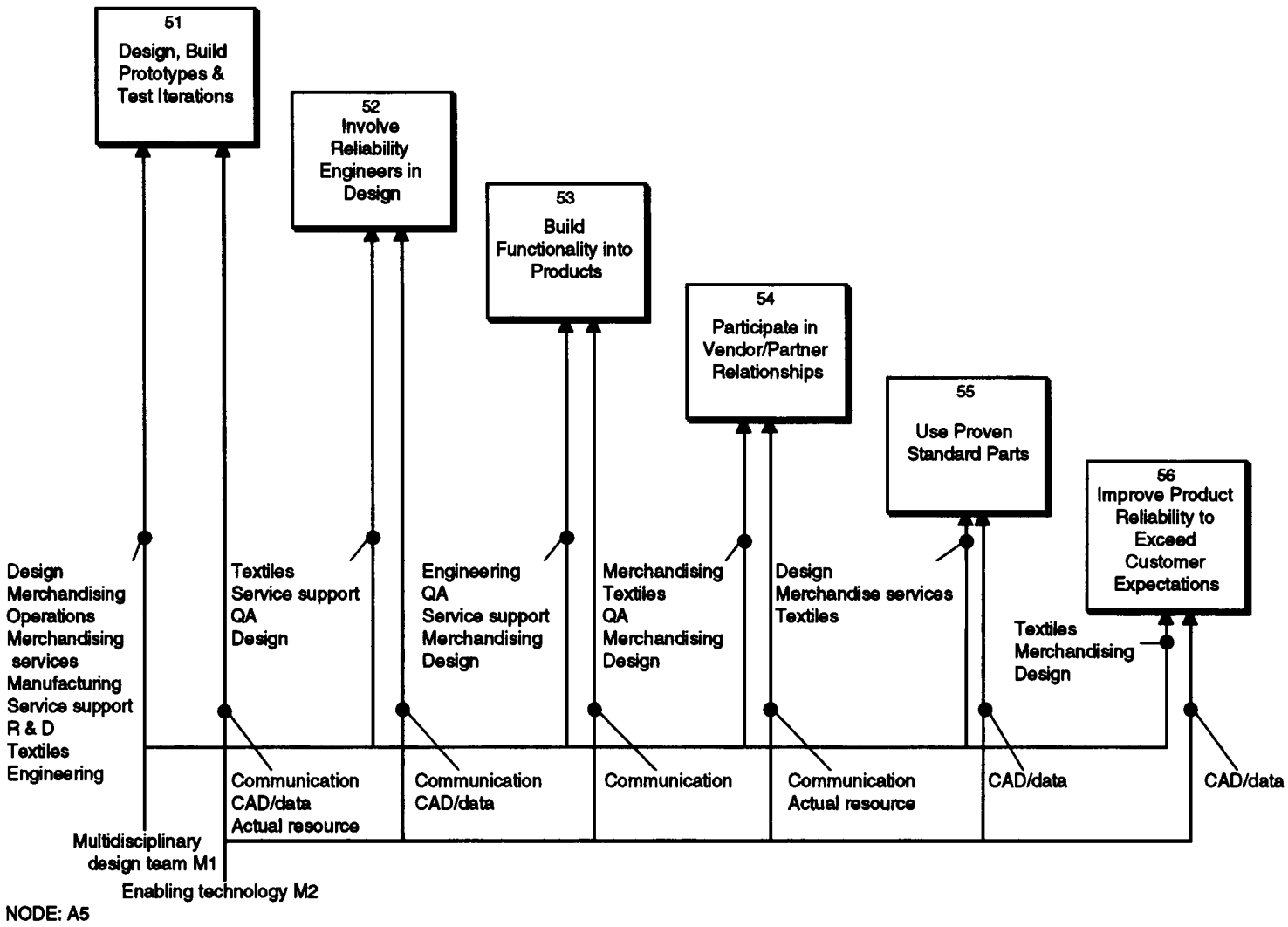
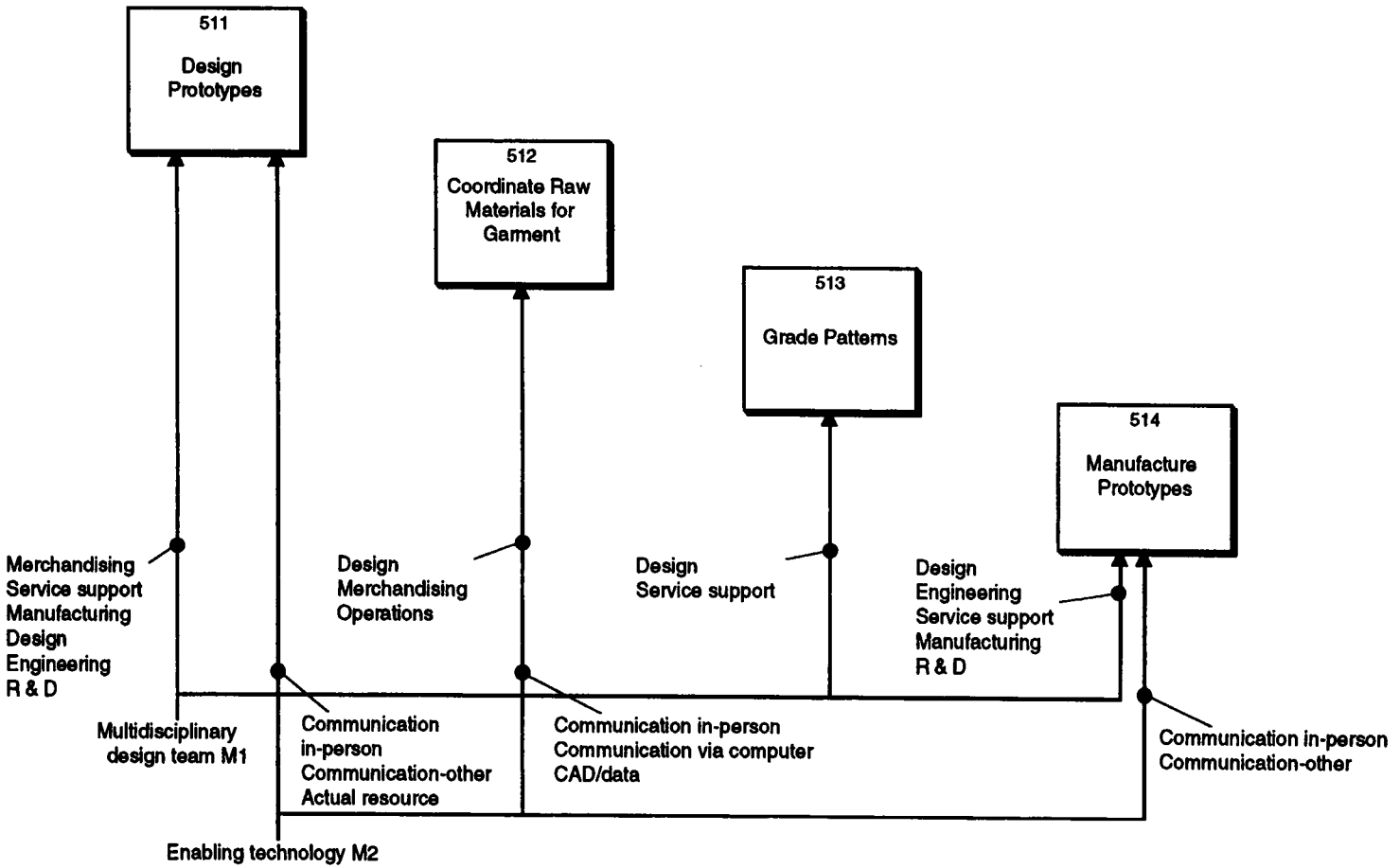
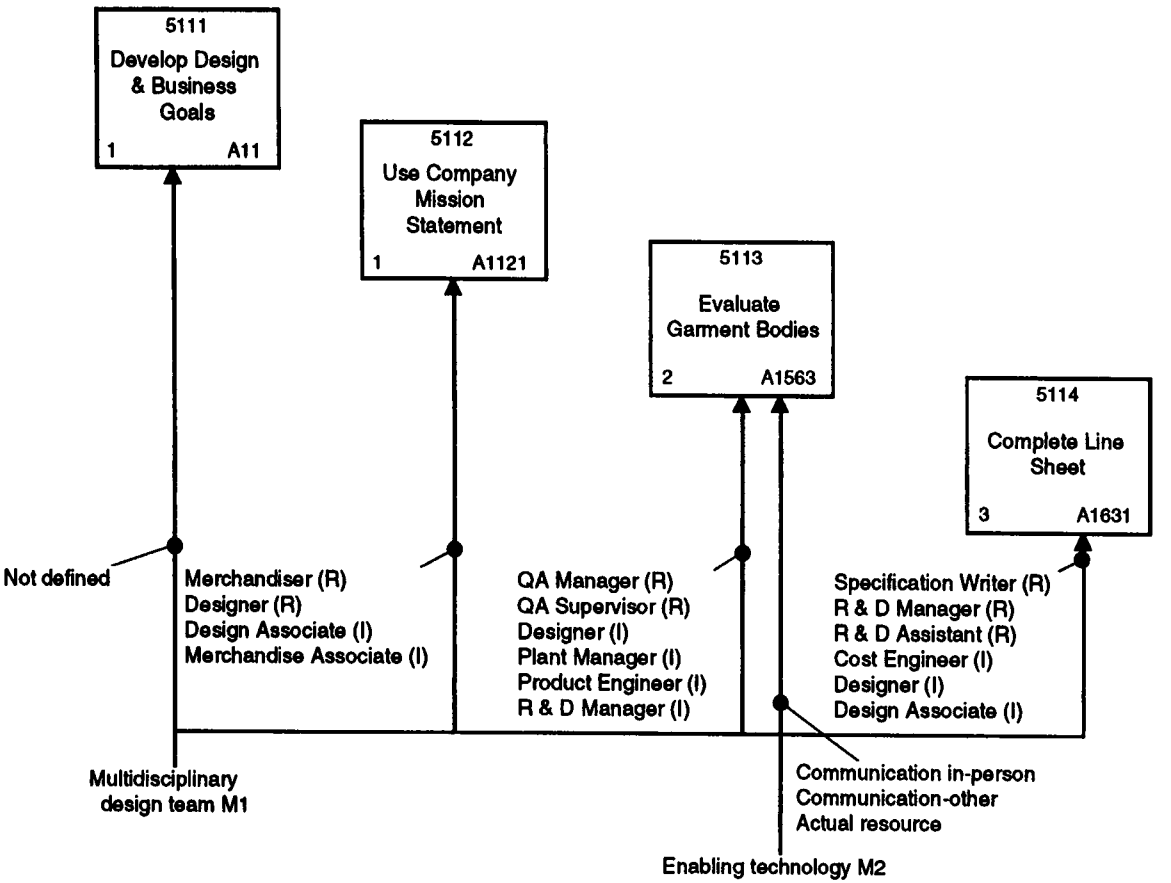


Figure 174. Design for life cycle reliability.



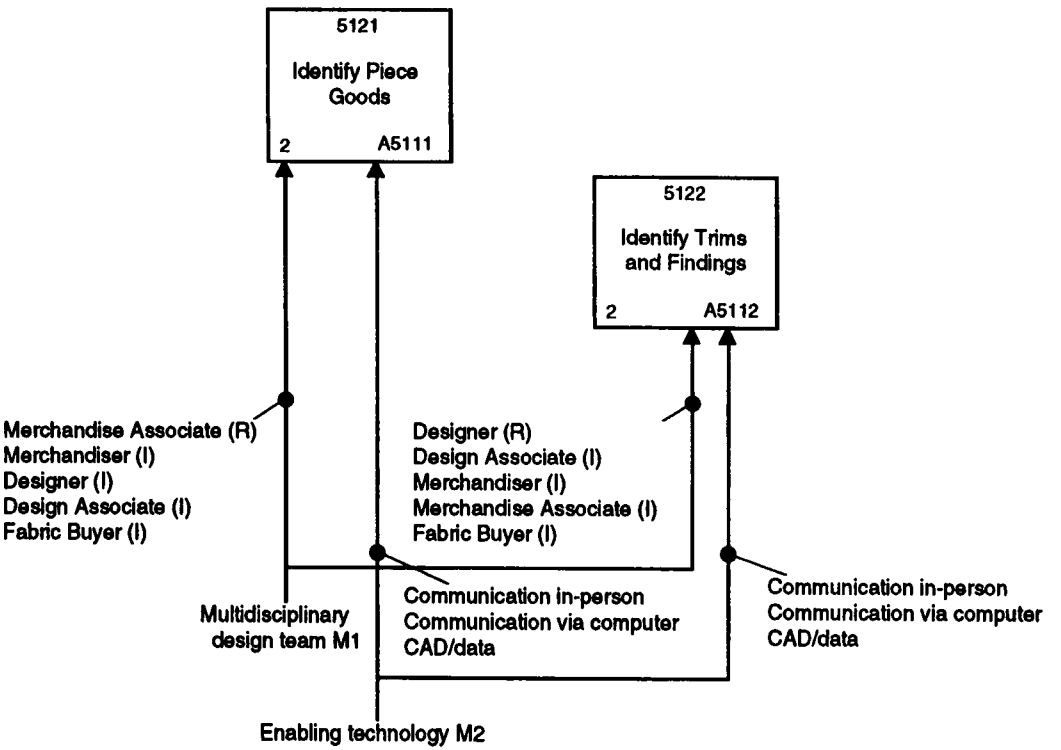
NODE: A51

Figure 175. Design, build prototypes and test iterations.



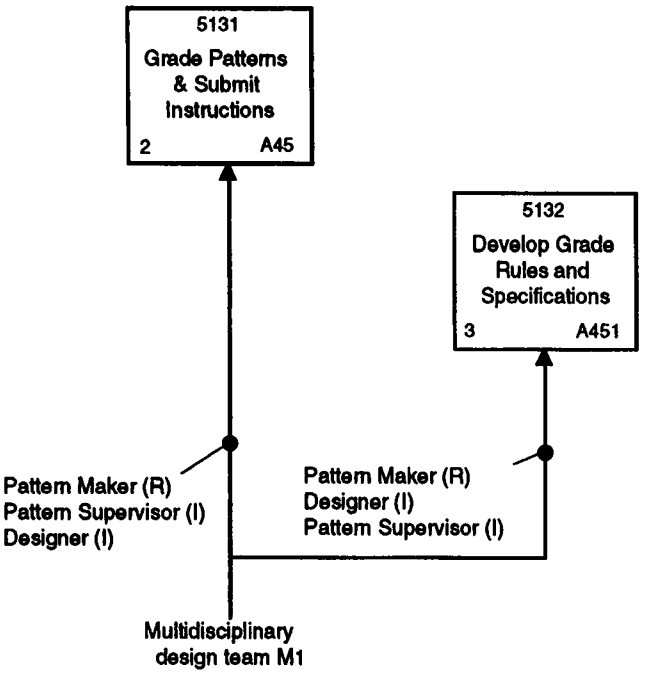
NODE: A511

Figure 176. Design prototypes.



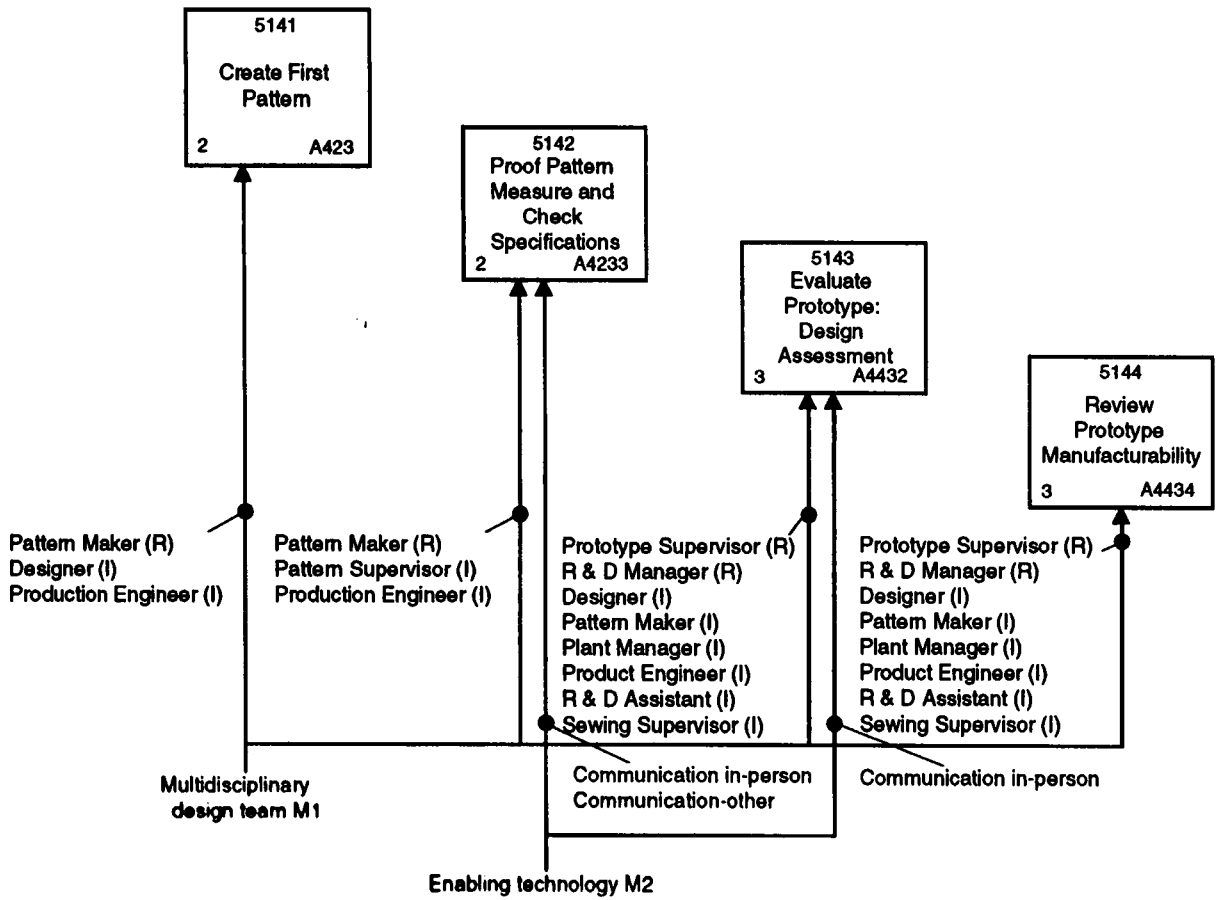
NODE: A512

Figure 177. Coordinate raw materials for garment



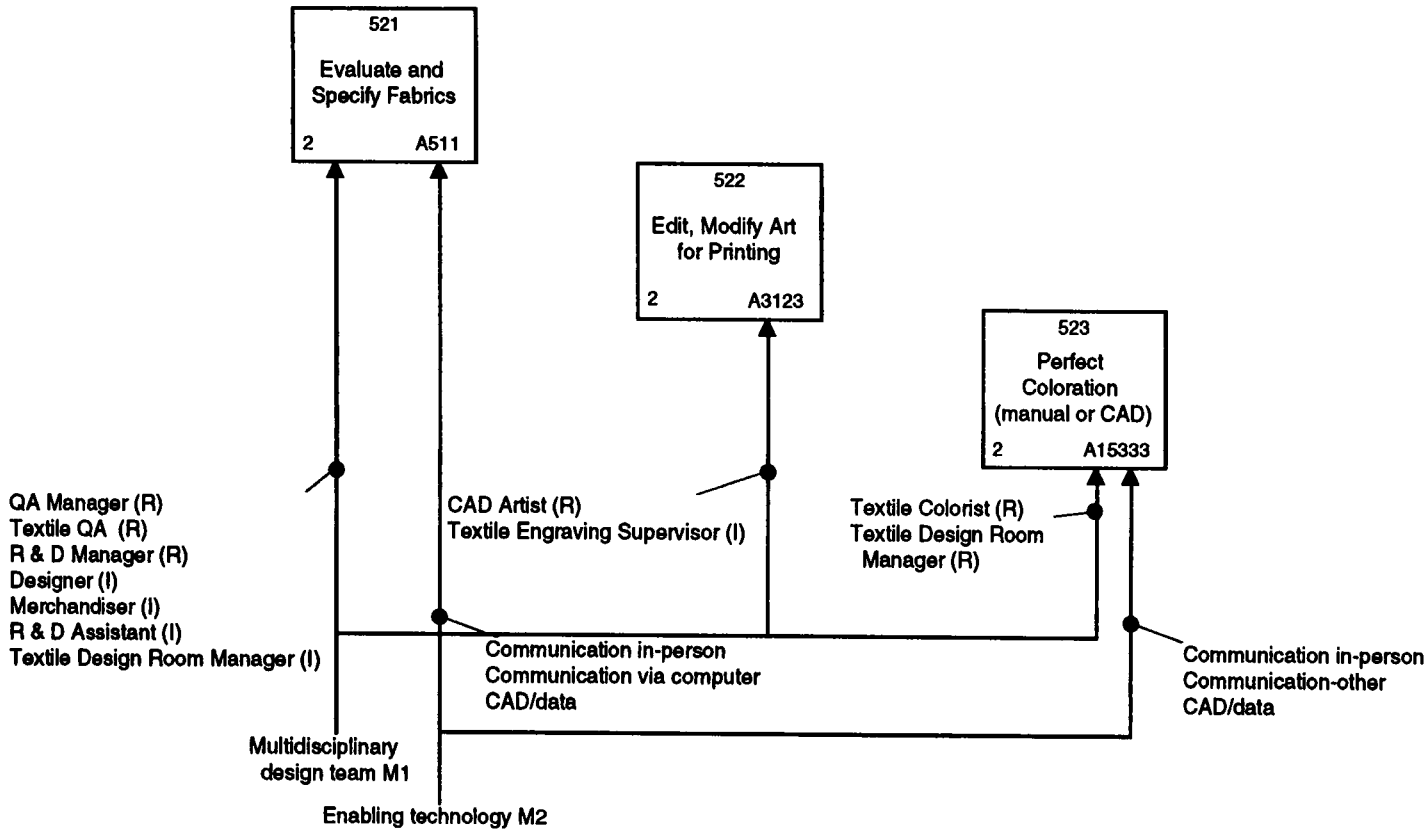
NODE: A513

Figure 178. Grade patterns.



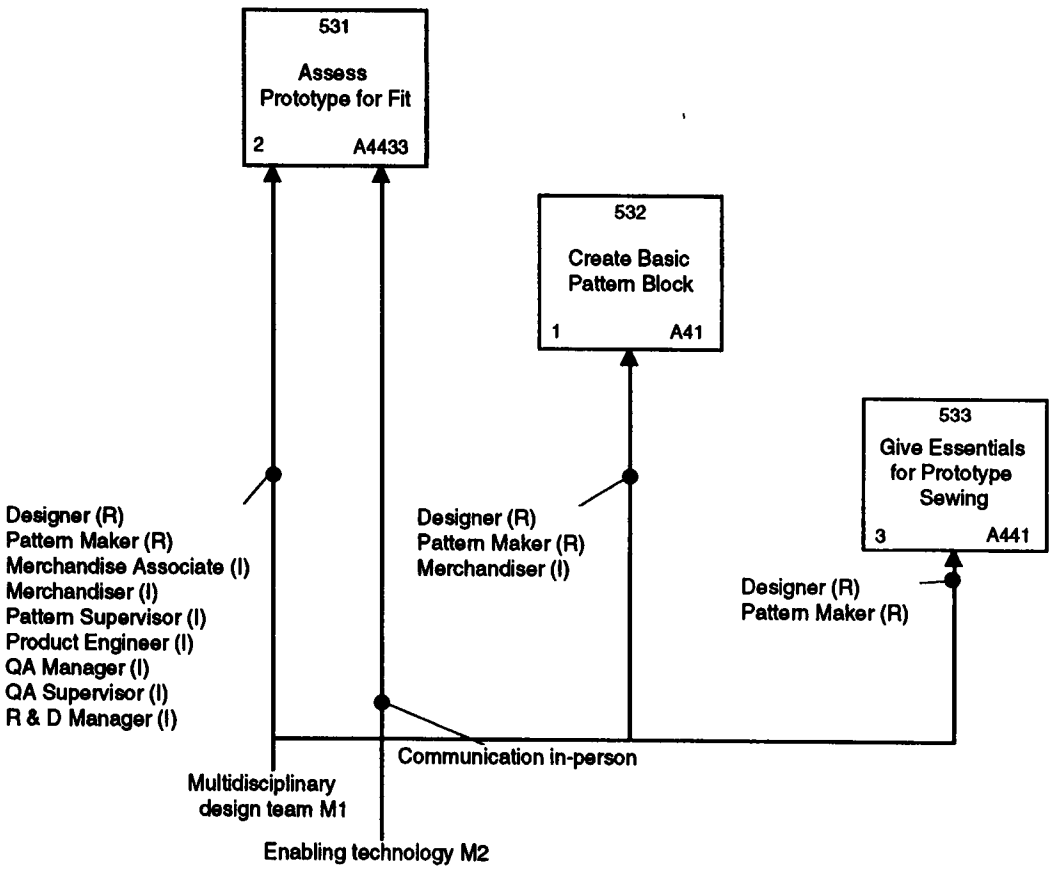
NODE: A514

Figure 179. Manufacture prototypes.



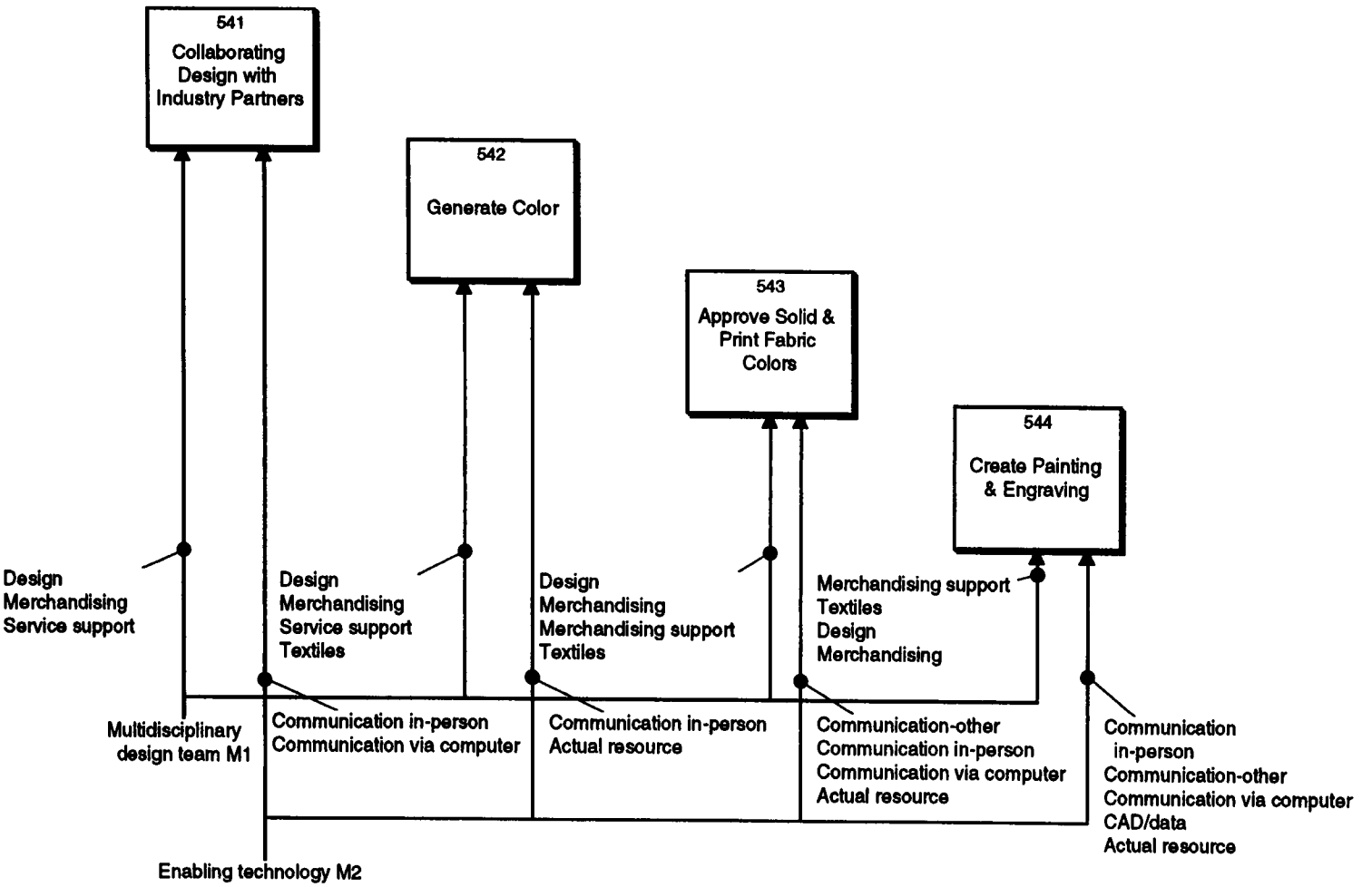
NODE: A52

Figure 180. Involve reliability engineers in design.



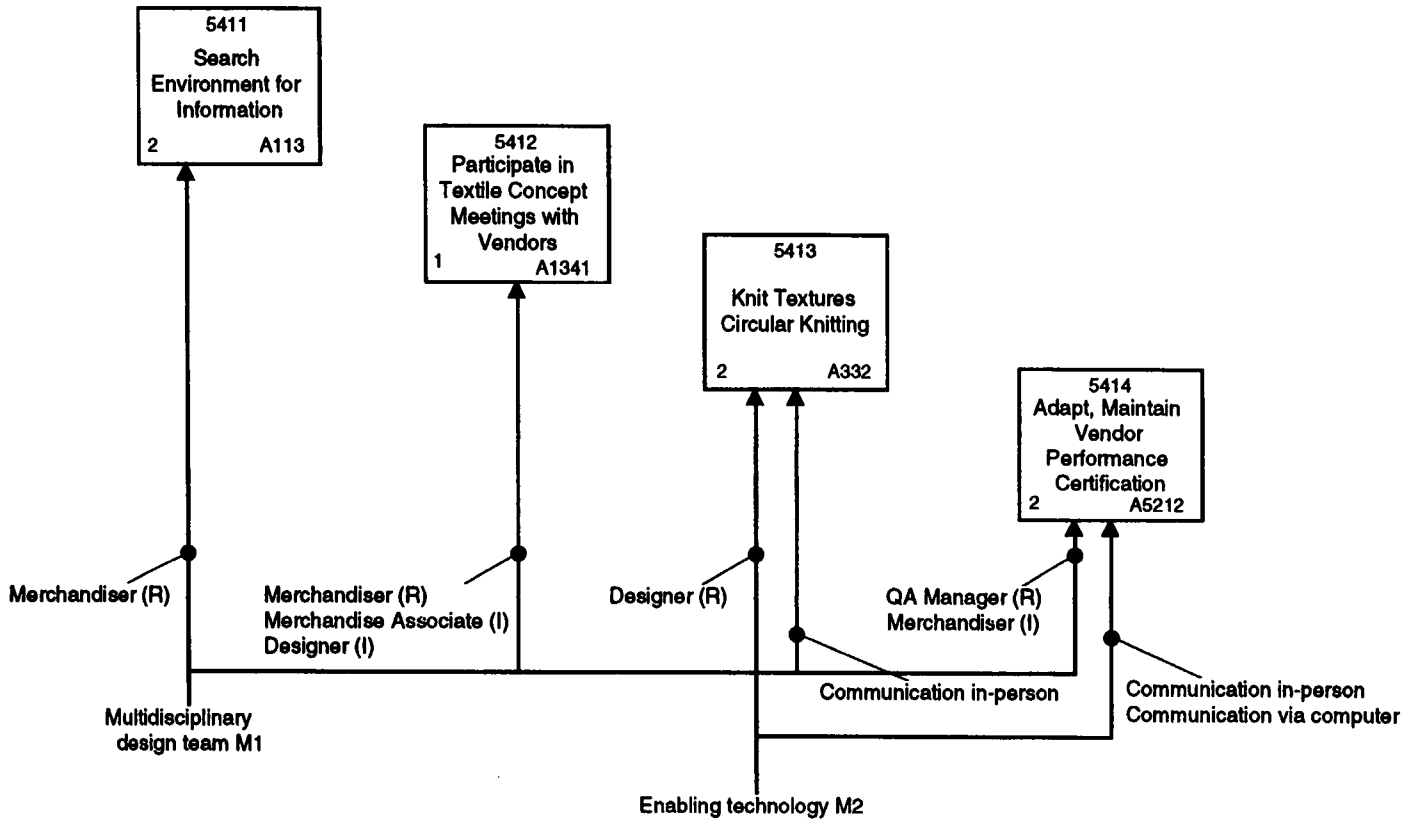
NODE: A53

Figure 181. Build functionality into products.



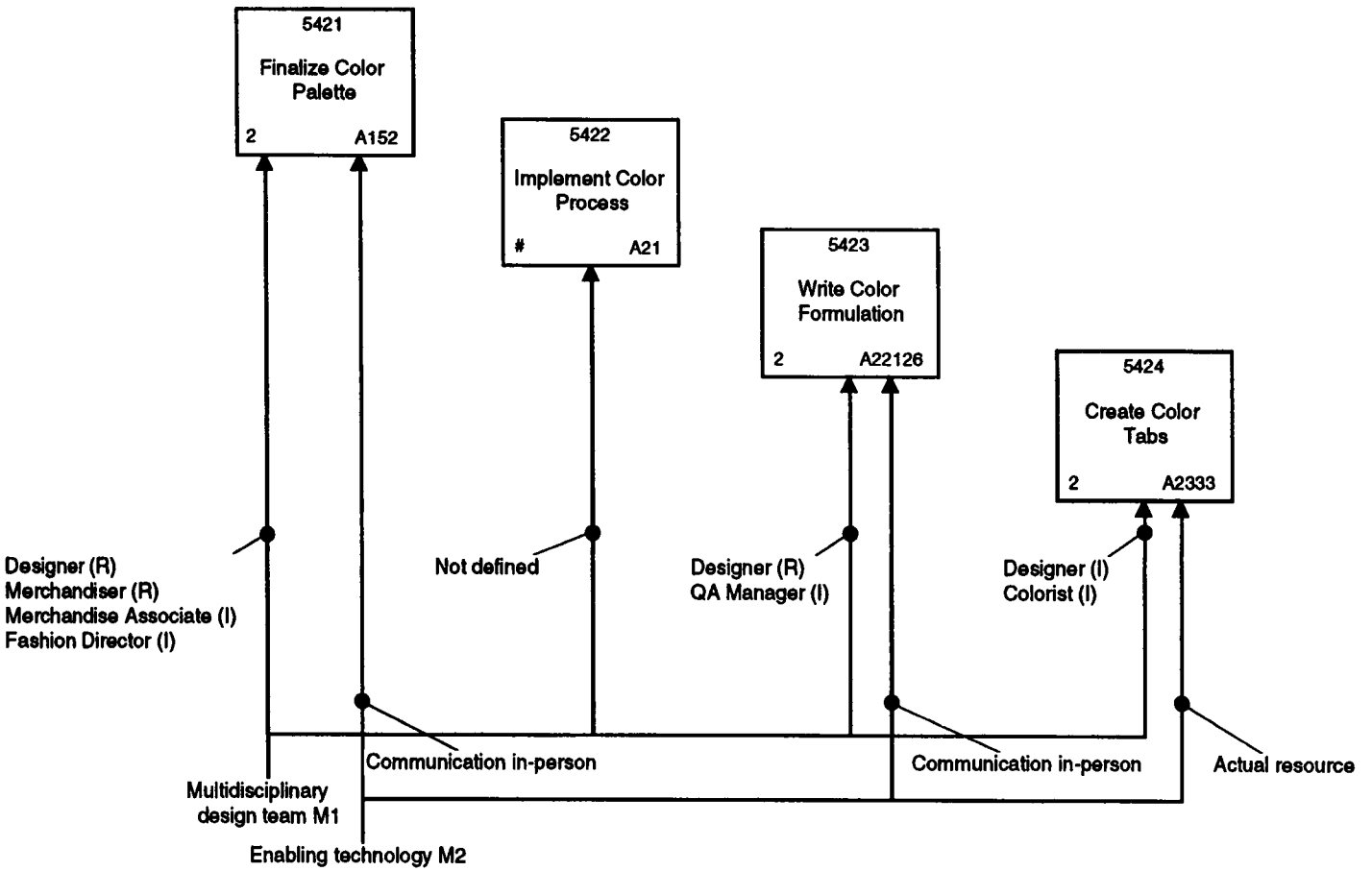
NODE: A54

Figure 182. Participate in vendor/partner relationships.



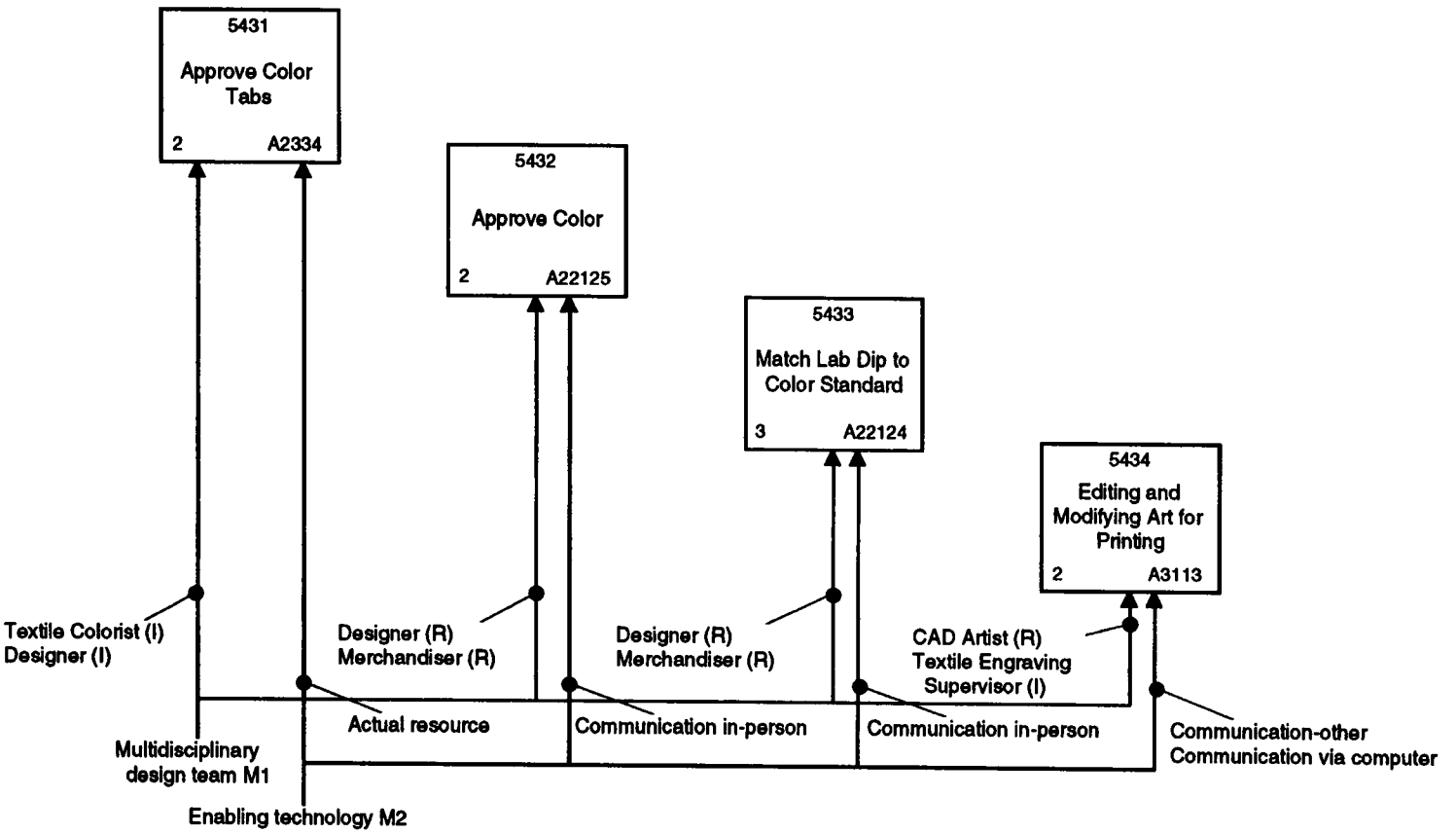
NODE: A541

Figure 183. Collaborating design with industry partners.



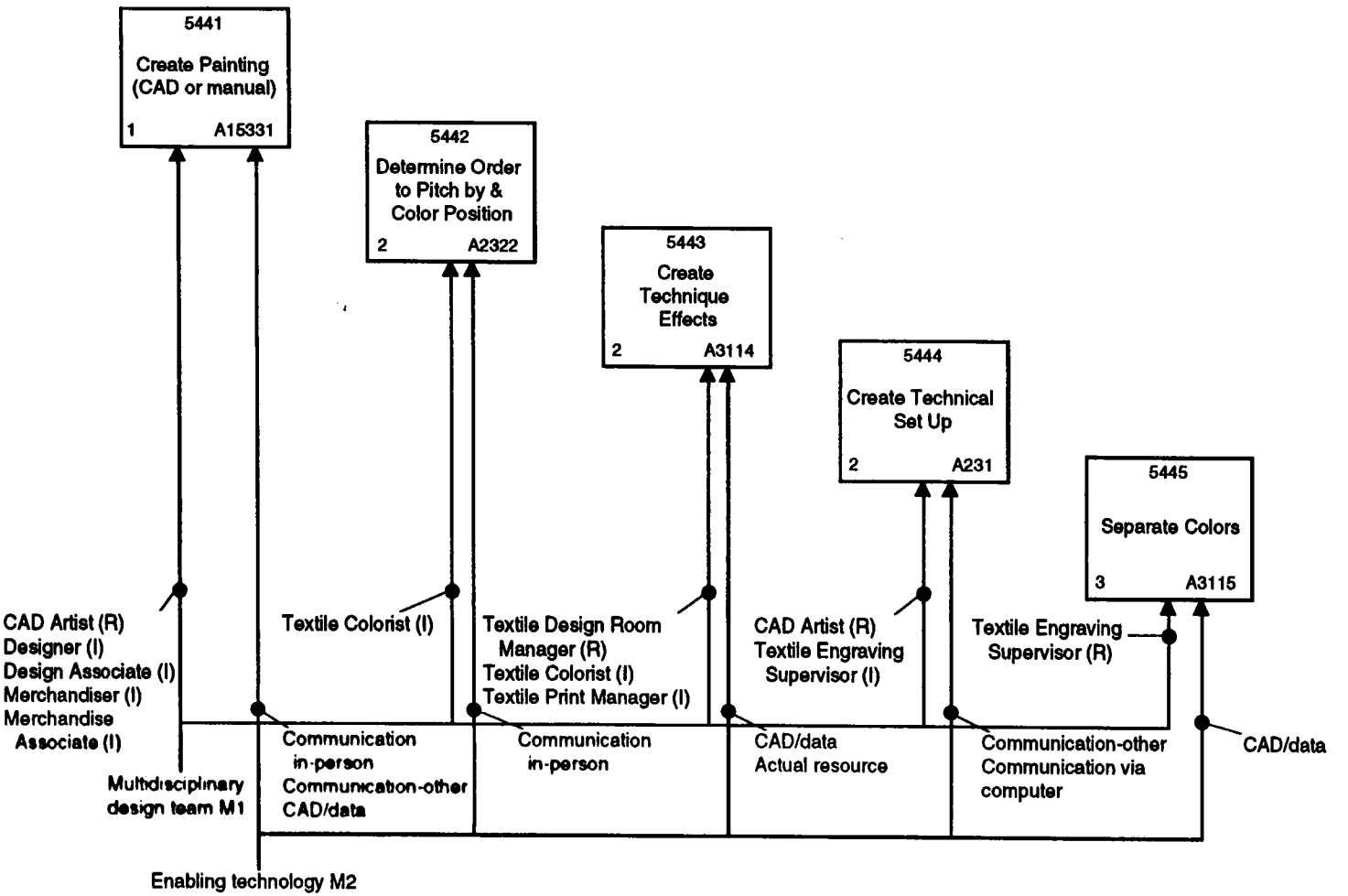
NODE: A542

Figure 184. Generate color.



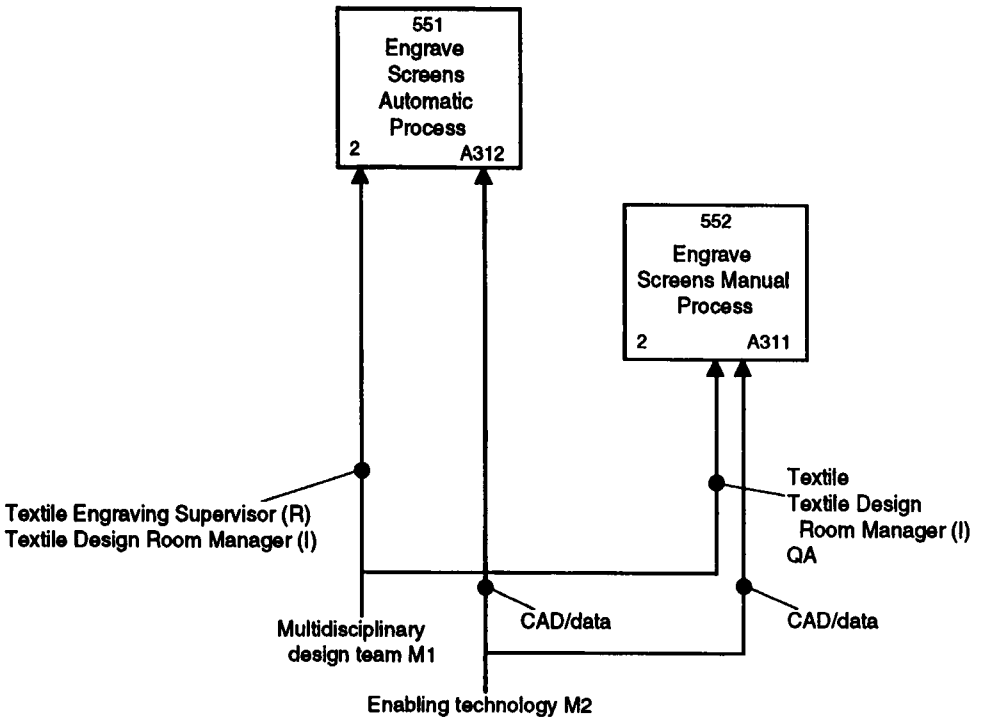
NODE: A543

Figure 185. Approve solid and print fabric colors.



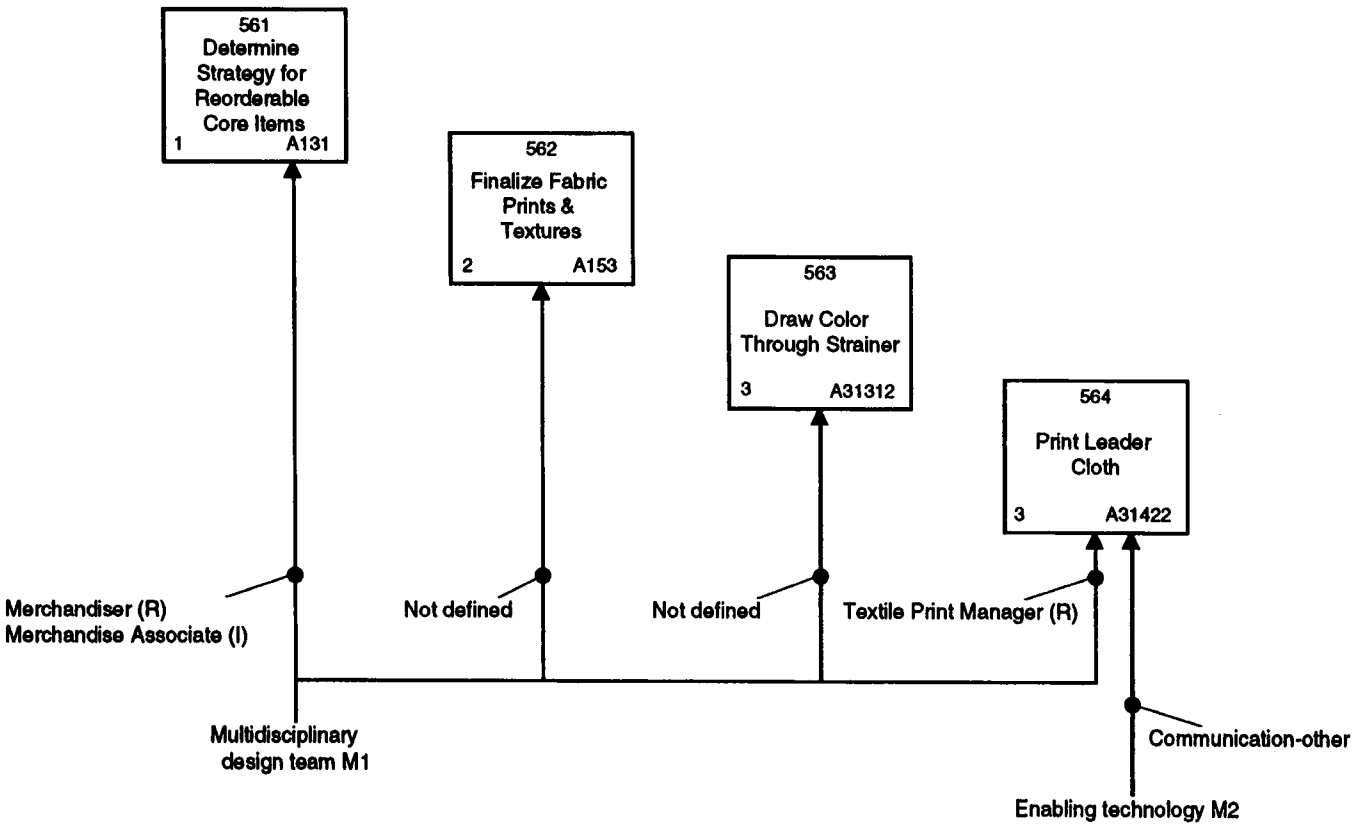
NODE: A544

Figure 186. Create painting and engraving.



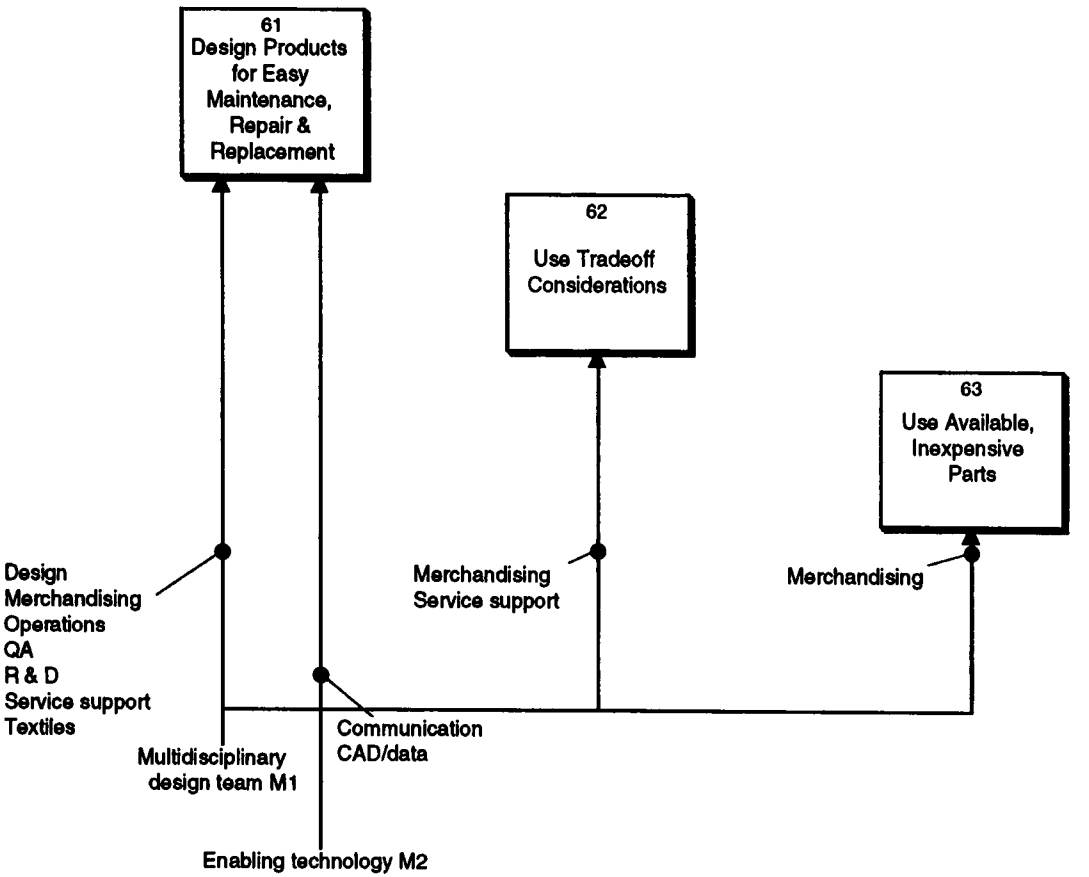
NODE: A55

Figure 187. Use proven standard parts.



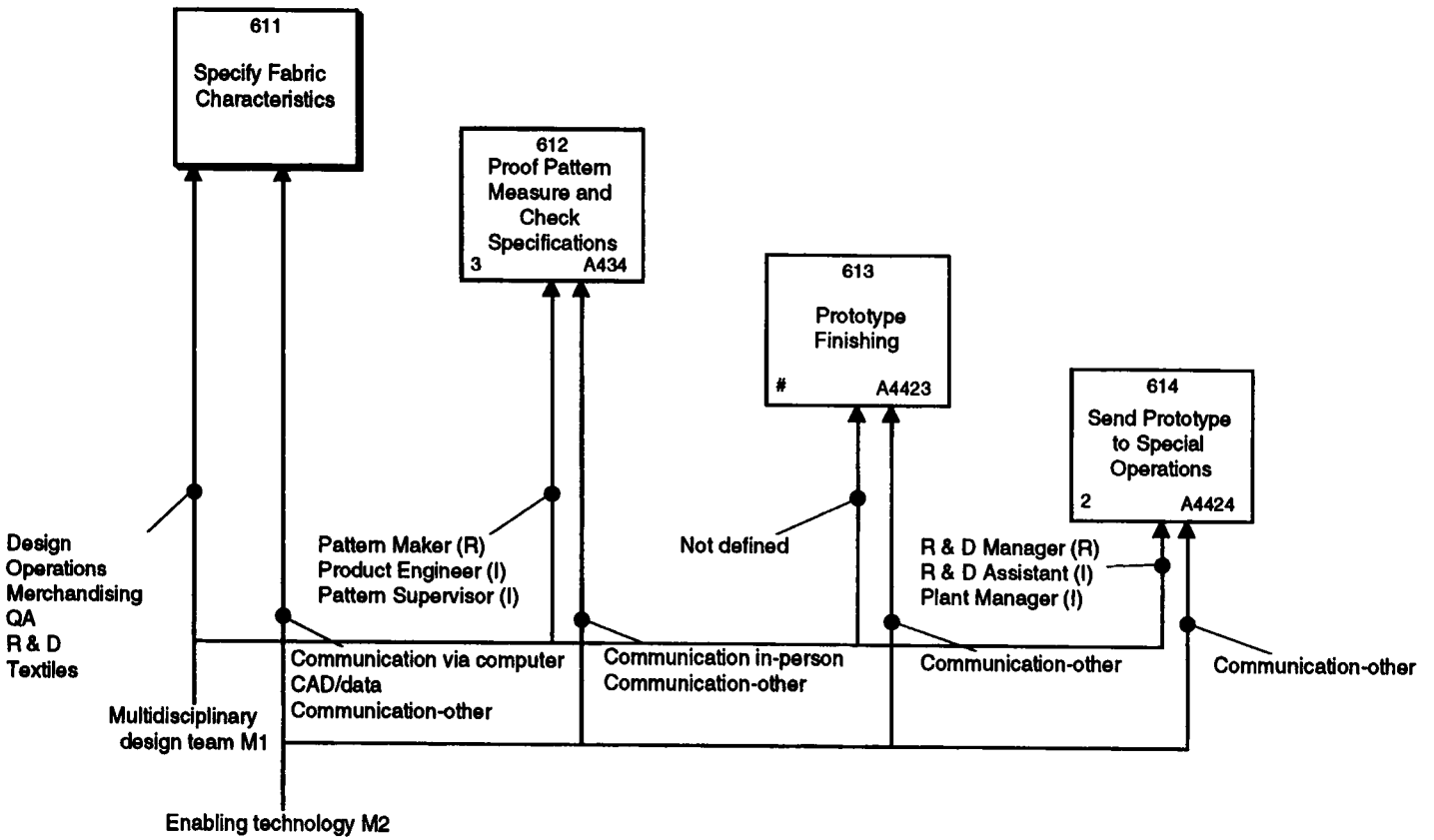
NODE: A56

Figure 188. Improve product reliability to exceed customer expectations.



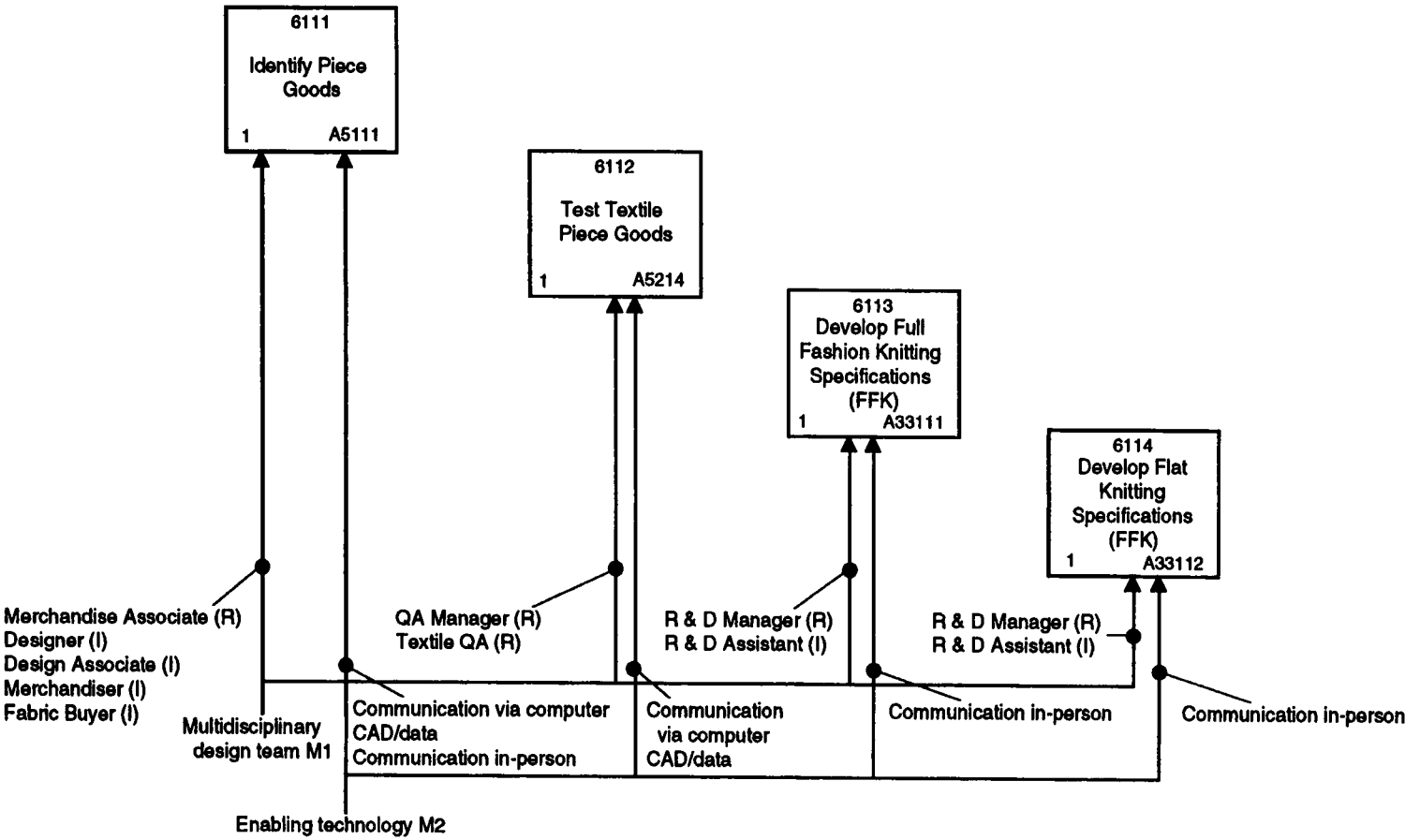
NODE: A6

Figure 189. Design for life cycle maintainability.



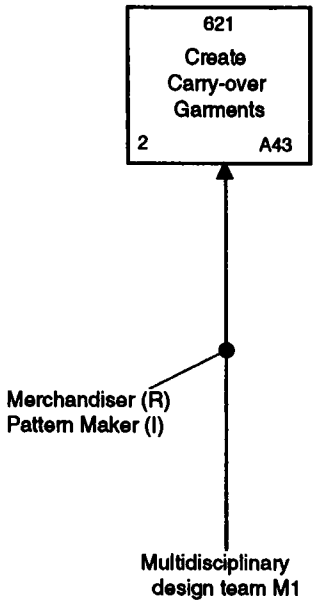
NODE: A61

Figure 190. Design products for easy maintenance, repair and replacement.



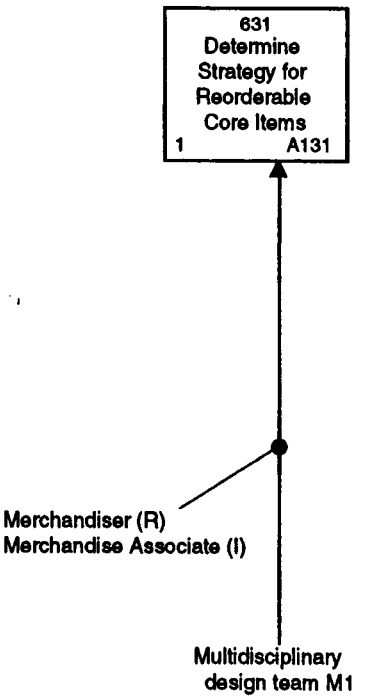
NODE: A611

Figure 191. Specify fabric characteristics.



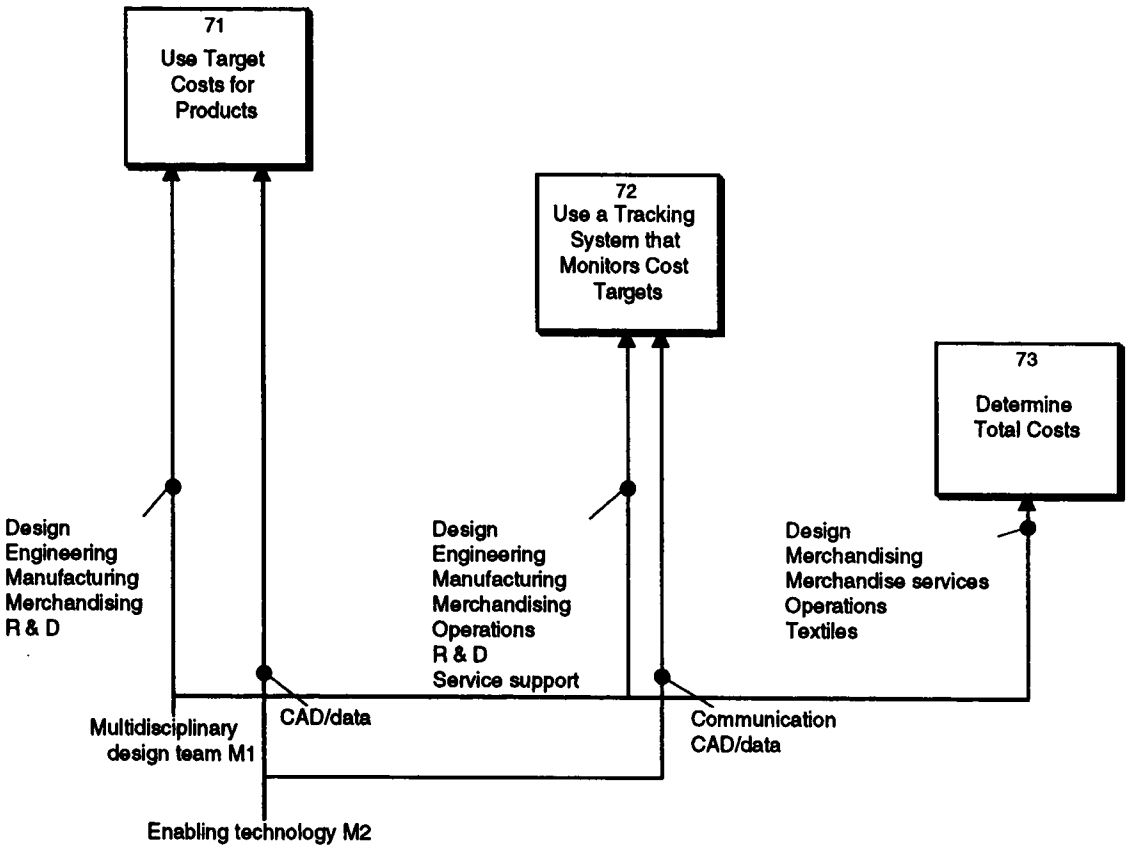
NODE: A62

Figure 192. Use tradeoff considerations.



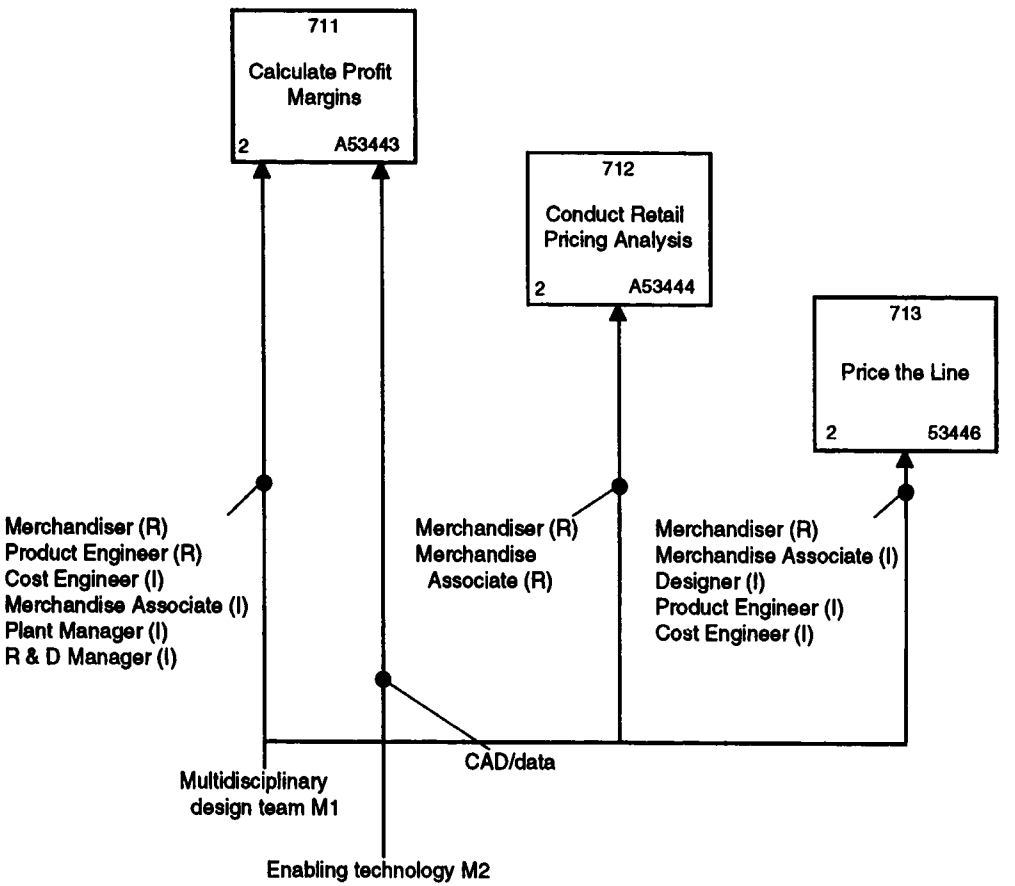
NODE: A63

Figure 193. Use available, inexpensive parts.



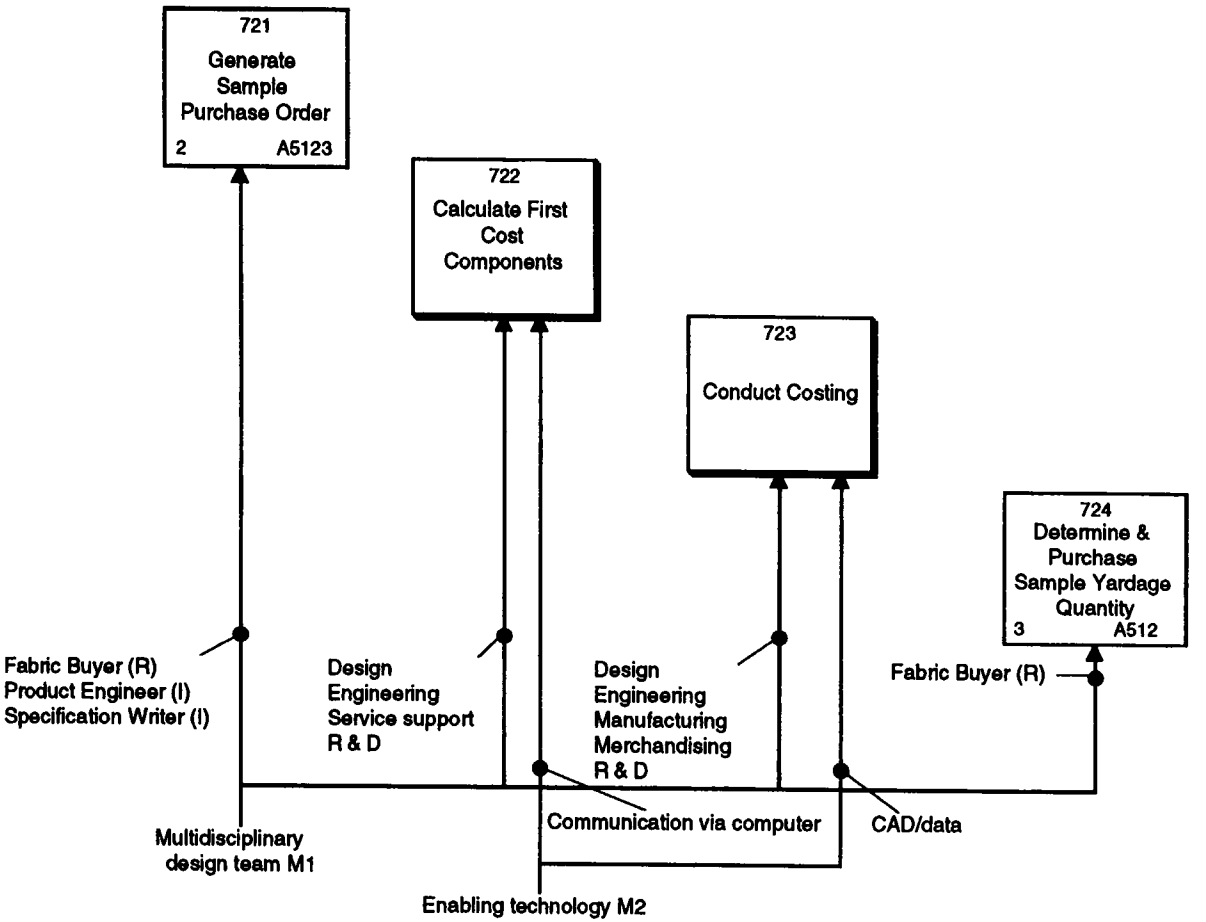
NODE: A7

Figure 194. Design for cost.



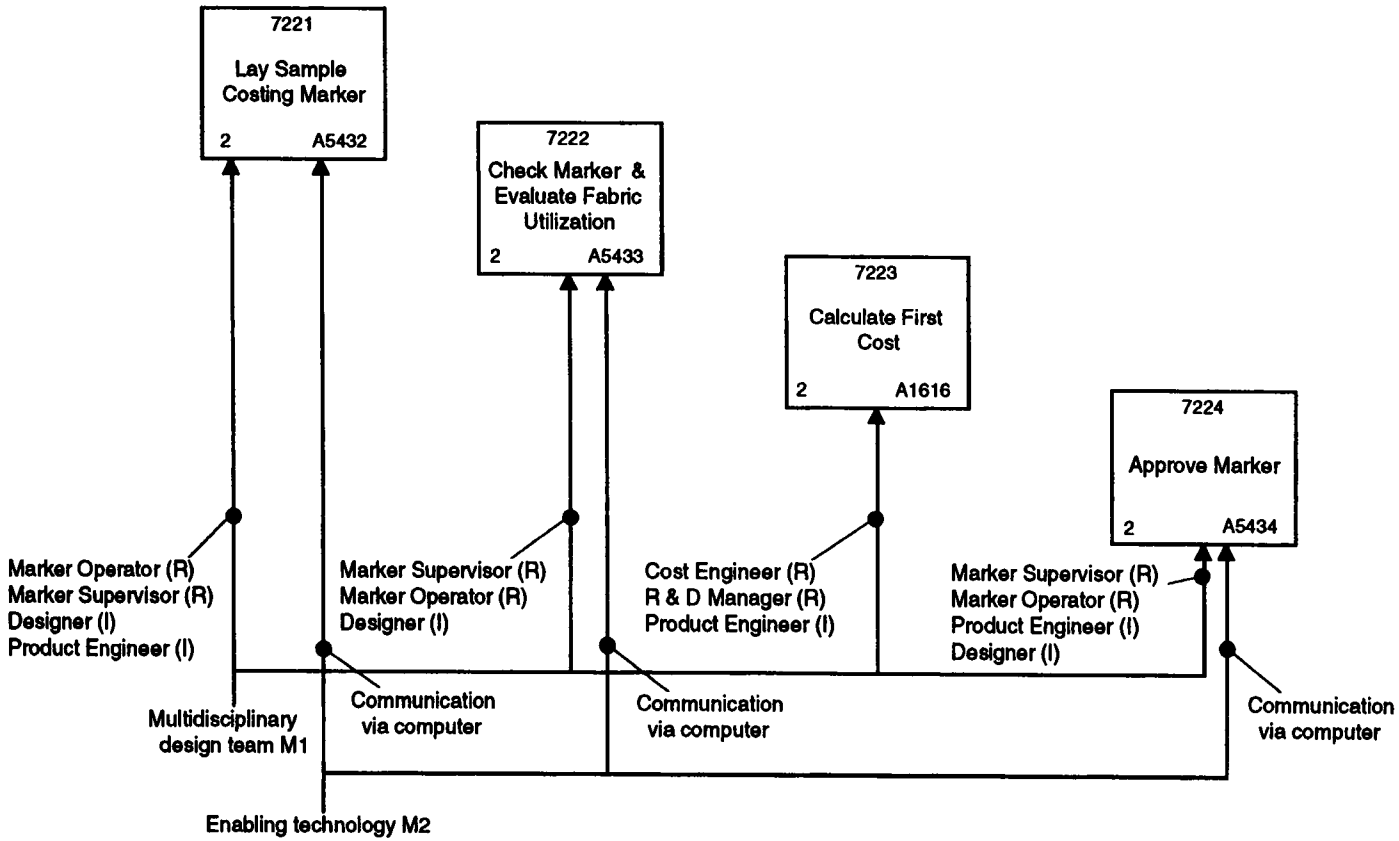
NODE: A71

Figure 195. Use target costs for products.



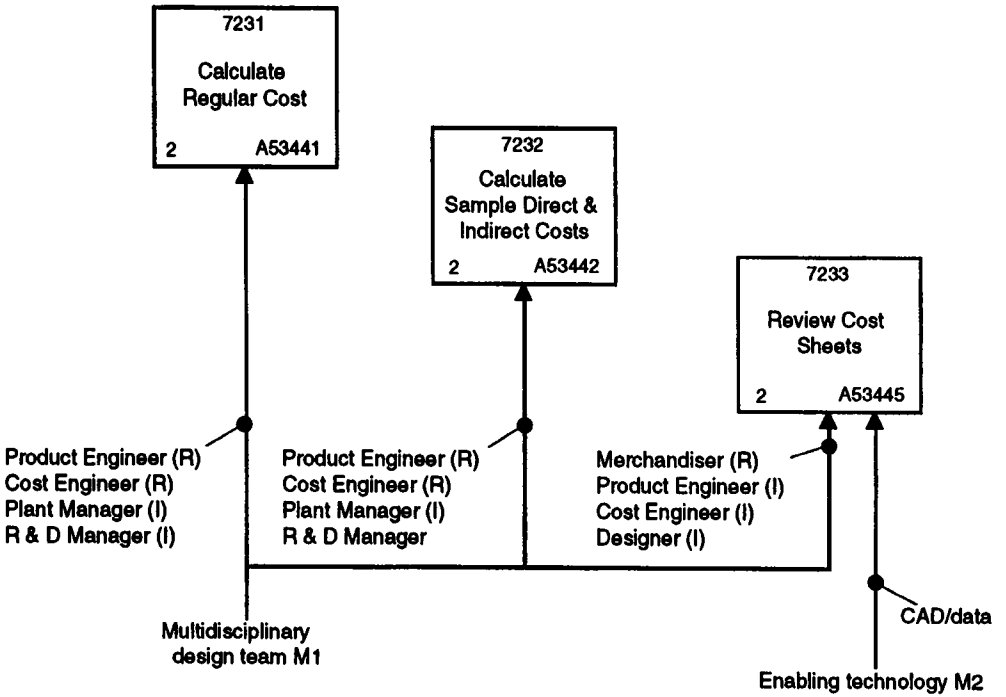
NODE: A72

Figure 196. Use a tracking system that monitors cost targets.



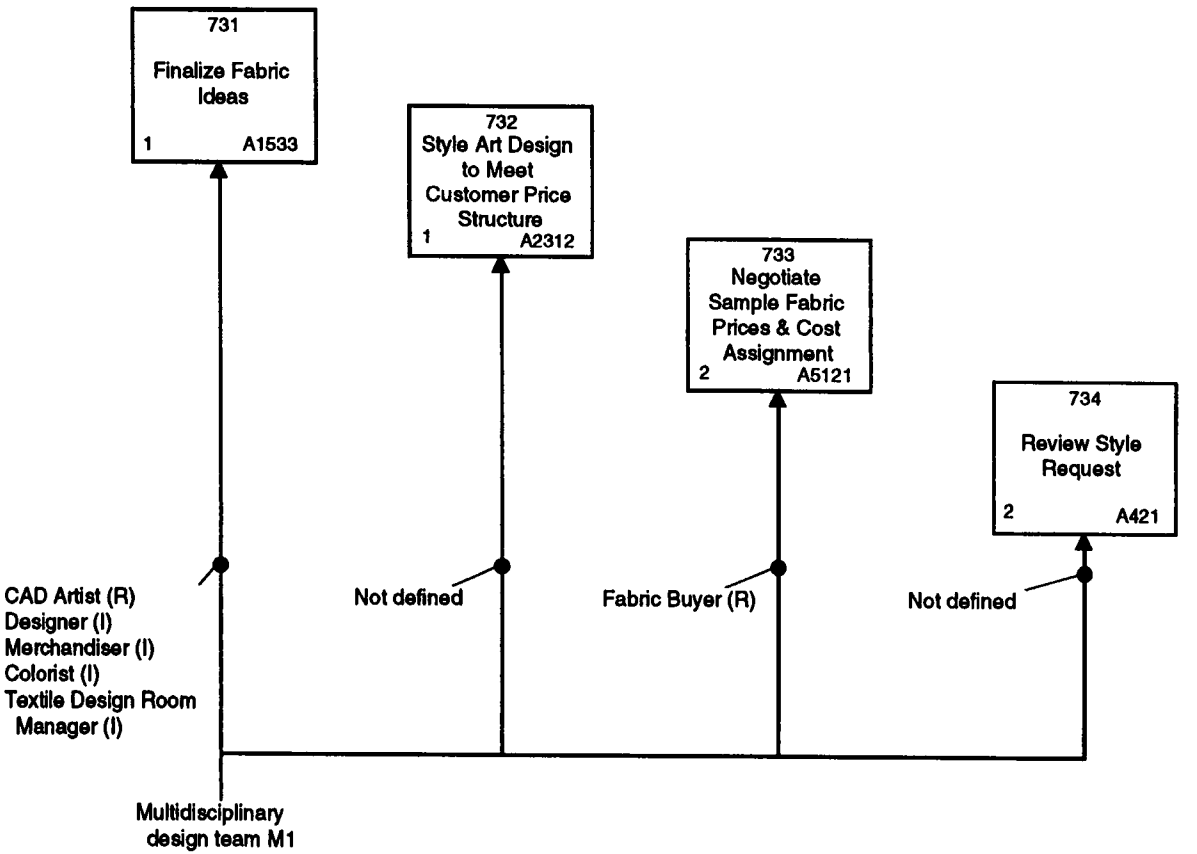
NODE: A722

Figure 197. Calculate first cost components.



NODE: A723

Figure 198. Conduct costing.



NODE: 73

Figure 199. Determine total costs.

CHAPTER VII. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of the present study was to develop a CE framework specifically for apparel manufacture. The researcher used an interpretational qualitative research case study approach to develop in-depth conceptual relationships for the apparel design and product development process. The current study used a purposive discriminate sample to obtain an in-depth study of apparel design and product development apparel associates. Seventy-two apparel associates from a variety of product development functional areas participated in data collection from three apparel manufacturers, three textile suppliers, and one customer. The research project had two phases of data collection. Phase One data collection documented the *as is* environment. A triangulated data collection method combined interviewing, reading company documents, and observing to collect data for Phase One. Phase Two data collection consisted of giving questionnaires to apparel associate focus groups. A total of 34 apparel associates participated in Phase Two to develop a *to be* environment by reorganizing existing apparel design and product development activities using the CE approach.

Phase One findings are the researcher's comprehensive mapping of the *as is* environment functional areas (i.e., current design and product development process) and process performance weaknesses. $IDEF_0$ analytic graphic diagrams are results that illustrate the *as is* environment functional activities, and ICOM. The narrative describes process replications and process performance weaknesses. Phase Two results and discussion of $IDEF_0$ findings are the reorganization of *as is* apparel activities, the inclusion of multi-disciplinary design teams, and the use of enabling technology (e.g., mechanisms) in a *to be* environment. Phase Two findings are presented in narrative and $IDEF_0$ analytic graphic diagrams. The $IDEF_0$ analytic graphic diagrams are illustrations of

the *to be* environment in which the researcher developed a CE framework to integrate the apparel design process with the product development process. The narrative includes a *to be* environment evaluation for projected process performance improvement. The projected performance improvement is based on questionnaire results from a focus group of apparel associates. The research internal validity was increased by the use of apparel associates validating the *as is* and *to be* environments.

The *As Is* Environment Summary

The researcher's review of clothing and textile literature indicates that a holistic, detailed documentation of design and product development is not available in published apparel literature. Frings (1994), Glock and Kunz (1990), and Kadolph et al. (1993) exemplify clothing and textile authors who have documented isolated portions of the apparel design and product development process. The lack of having represented apparel activities across the entire product development spectrum created a need for a comprehensive apparel design and product development model. Consistent with Pawar and Driva (1996), the present study documents and verifies the *as is* environment from design concept through sample production. An *as is* environment documentation was necessary to implement Phase Two research.

A study that documents the *as is* environment and develops a *to be* environment is justified by apparel industry literature on competitiveness. U.S. apparel employment has decreased since the 1970s ("News Notes," 1996) and annual U.S. apparel sales have decreased since the 1980s (Brown, 1996; Commission Working Group, 1989). Even with the U.S. apparel industry's decreasing employment and decreasing sales trend, the U.S. Department of Labor (1994a) predicts that most apparel will continue to be designed in the U.S. However, Moncarz (1992) reported that the apparel design and product development process is inefficient and needs research. Design and product development

impact manufacturing more than any other singular process (Wheelwright & Clark, 1992). The design process accounts for only 5% of the product cost; however, it indirectly controls 75% to 80% of total product cost (Carver & Bloom, 1991; Whitney, 1988). A product's profitability is lessened by costs of rework, time delays, and hidden costs (Blanchard & Fabrycky, 1990).

Phase One data research design for the *as is* environment is a qualitative descriptive study. The researcher did not attempt to control the research setting; rather, the researcher used a case study approach to document the complexity of the design and product development process. The *as is* environment findings are represented in 101 $IDEF_0$ analytic graphic diagrams and process performance narrative. The *as is* environment is divided into six major functional areas: create apparel line (A1), develop colors and prints (A2), implement fabric design and special operations (A3), create garment pattern and prototype (A4), set production specifications (A5), and produce samples (A6). Each functional area includes detailed ICOM. Process constraints in $IDEF_0$ diagrams are shown by the sequence of activities, inputs, and controls for 434 specific functional activities. The narrative provides explanation of the number of replications for each major functional area. The functional activity replication documents process complexity in creating a seasonal apparel line.

During data collection and analysis, the researcher found that having an apparel manufacturer sample that represents different industry sectors added breadth to the results. The present study's $IDEF_0$ diagrams document a wide representation and a comprehensive view of functional activities that take place within apparel design and product development. A breadth of fabric processes is represented in implement fabric design and special operations (A4). This set of operations includes the diverse activities of woven and knit rotary screen prints, woven and knit engineered fabric prints, knit full

fashion, and knit circular textures. For example, rotary screen print fabric (A31) and solid piece dye for yard goods (A22) functional activities are both represented in the *as is* environment. While one apparel manufacturer may refer only to woven print fabric functional activities, another apparel manufacturer may use and refer to both rotary screen print fabric and solid piece dye for yard goods.

The researcher used interviewing for the primary data collection method. Triangulated data collection methods are incorporated by supplementing interview data with researcher observation of apparel associates and company documents. Research integrity is achieved through triangulated data collection methods and results validation. The present study uses triangulation methods by including multiple companies, using multiple data collection techniques, and interviewing multiple subjects on the same topic. The multiple companies in the sample manufacture basic or fashion products and represent men's, women's, and children's wearing apparel. During data collection, interviewing multiple subjects on the same topic provided better insight into functional activities and ICOM for the *as is* environment. For example, when the researcher interviewed one textile colorist, that interview became a guide for an interview with a second textile colorist. During data collection, interviewing multiple subjects clarified and completed a represented process. Other subjects added breadth and ensured an accurate description of a particular process by providing additional information about a specific apparel associate's (e.g., textile colorist) role in the *as is* environment process.

To ensure accurate representation on $IDEF_0$ diagrams, the researcher transcribed all interviews and validated the data. During data analysis, the researcher cross-referenced multiple transcripts for represented functional areas. The written transcripts helped the researcher converge data during analysis. For example, in analyzing the create garment pattern and prototype functional area (A4), the researcher cross-referenced all pattern

making and prototyping transcripts. The researcher combined the cross-referenced information to develop the functional activities in the *as is* environment $IDEF_0$ diagrams.

Through $IDEF_0$ diagram validation, the researcher developed an accurate representation of the *as is* environment for the companies in the sample. Apparel associates in the sample reviewed $IDEF_0$ analytic diagrams and validated the study's results. The validation process allowed the researcher the opportunity to correct the sequence and accuracy of ICOM and functional activities. By using multiple data collection methods, cross-referencing multiple subjects, and validating results, the researcher is reasonably assured that the findings could be replicated if another researcher conducted a similar study.

The *as is* environment findings identify process performance weaknesses for time-to-market delays, excess cost, and decreased process quality. Identifying *as is* environment process performance weaknesses is in concert with Pawar and Driva's (1996) recommendation for process capture. The researcher used the line development calendar as a guide to interview apparel associates on time-to-market delays. Process quality and excess cost data analysis in the present study are restricted to implied decreased process quality and implied excess cost as documented by the subjects. Apparel associates indicated that time-to-market delays, excess cost, and decreased process quality were due to rework activities, nonvalue-added activities, and process delays.

The *To Be* Environment Summary

Phase Two research develops an integrated apparel product development process (i.e., *to be* environment). Many durable and consumer goods industries have experienced success with CE implementation; however, the researcher's review of literature showed no applications where CE has been used for apparel manufacture. Reported benefits of

CE are improved quality, reduced product development time, reduced costs, fewer defects, and reduced rework (Lawson & Karandikart, 1994; Rosenblatt & Watson, 1991; Syan, 1994).

The *to be* environment (e.g., integrated product development process) is represented in 80 $IDEF_0$ analytic graphic diagrams and 292 functional activity boxes. The foundation for Phase Two is the researcher's review of CE literature and published CE analytic graphic models (Crow, 1992; Hyeon et al. 1993; Schmitz & Desa, 1992; Sharon, 1992; Turino, 1992). The *to be* environment is divided into seven CE conceptual statements, which are: design for quality, enabling technology, manufacturability, life cycle-inspectability, life cycle-reliability, life cycle-maintainability, and cost. Lower level $IDEF_0$ drawings decompose the CE conceptual statements into CE operational statements and apparel activities. The $IDEF_0$ diagram findings identify potential multi-disciplinary teams and the use of enabling technology for apparel activities.

The researcher developed and gave questionnaires to apparel associate focus groups in order to collect data for the *to be* environment process. The data collection instruments used to create the *to be* environment were a CE constructs questionnaire (i.e., CE operational statements), Q-sort, multi-disciplinary team questionnaire, and enabling technology questionnaire. To create the CE apparel framework, the apparel associates used a Q-Sort (i.e., a comparative scaling technique) to categorize and group *as is* apparel functional activities into CE conceptual statements. Apparel associates then ranked the sorted apparel activities within each CE conceptual statement. Apparel associates ranking activities into early (1), middle (2), and late (3) within each CE conceptual statement. During data analysis, the researcher evaluated the early, middle and late ranking of apparel activities to determine whether apparel activities moved from their position in the *as is* environment and to create a new design maturity curve.

The researcher used descriptive statistics to analyze Phase Two data. To refine data analysis, the researcher used heuristics. Further data analysis refinement was obtained by apparel associates' *to be* model validation. Phase Two research integrity is achieved by the use of an acceptance cut-off, apparel associates' CE framework validation, and apparel associates' potential process performance evaluation. During data analysis, the researcher set an acceptance cut-off to accept Q-Sort apparel functional activities into CE conceptual statements. The acceptance cut-off for each functional activity was its selection by a minimum of 30% of the apparel associates for two out of the three companies. The researcher's use of CE operational statements refined the apparel activity grouping. The researcher used heuristics to group and categorize apparel activities into CE operational statements. The apparel associate focus groups validated the researcher's heuristics. Two apparel associate focus groups reviewed the *to be* environment $IDEF_0$ diagrams and validated or reorganized some apparel activities within CE operational statements. The apparel associates' validation is incorporated into the *to be* $IDEF_0$ diagrams. The same apparel associate focus groups evaluated the *to be* environment for potential process performance improvements. The apparel associates evaluated projected process performance for time-to-market delays, avoiding excess cost, and improving process quality. Upon apparel associate validation, the researcher drew the $IDEF_0$ diagrams using a flowchart software program.

Phase Two findings include ranking of the apparel activities into early, middle, or late for each CE conceptual statement. The ranking shows which activities can be accomplished concurrently within each CE conceptual statement. Consistent with Turino's (1992) CE design process model, the present study's findings document that apparel design activities are integrated with design support activities in the *to be* environment. The *to be* environment apparel concurrent activities cross over functional

boundaries that are represented in the *as is* environment. By crossing over the functional boundaries, the *to be* design phase has early involvement from multi-disciplinary design teams who represent design, engineering, manufacture, merchandising, pattern making, quality assurance, and textiles.

Conclusions

The detail represented on *as is* environment $IDEF_0$ diagrams is a new contribution to clothing and textile literature. Phase One findings contribute to clothing and textile literature, because the $IDEF_0$ diagrams detail the intricacies and complexities of the apparel design and product development process. The *as is* environment represented in $IDEF_0$ diagrams interlink the varying aspects of apparel line creation (A1), color development (A2), fabric implementation (A3), pattern and prototype creation (A4), production specifications (A5), and sample production (A6). A distinct advantage of representing apparel functional activities and corresponding inputs, controls, outputs, and mechanisms shows what activities are constraints in the *as is* environment. Create apparel line (A1) is a major constraint in the process because all of the product development activities need inputs from its functional activities.

The findings document that the apparel design and product development process is complicated, with no easy answer for process performance improvement. The findings indicate that the *as is* environment is a sequential manufacturing process. The apparel manufacturers worked on four primary product development cycles within a one-year time period: spring, summer, fall, and winter/holiday. The average time to develop an apparel line was 32 weeks. During line development, the apparel associates worked on two to three overlapping product development cycles. The complexity of apparel manufacture is primarily due to the number of products designed (i.e., 50 to 350

manufacture styles per season) within a short time period. Designers are extensively involved in the entire *as is* environment. The $IDEF_0$ diagrams document that designers are represented in over 50% of the 101 *as is* environment $IDEF_0$ diagrams. The extensive designer involvement is primarily for functional activities that ultimately create final outputs for garment sample, sample approval, and sales package. The findings indicate that designers replicate 91 separate functional activities for each manufacturing style that is developed in a season. Consequently, designers are overburdened with decisions in the *as is* environment. For one season, a single designer is responsible for designing 50 to 350 selling styles. A designer's involvement and associated decision making equates to a minimum of 50 times 91 functional activities to a maximum of 350 times 91 functional activities to design a seasonal apparel line.

The findings indicate that overburdening designers with decisions is one reason for submitting inputs in batches and peak time periods from apparel line creation (A1) to other product development areas. The peak submittal of inputs is consistent with the detrimental *over the wall* approach in sequential manufacture. Menon (1992a) and Syan (1994) indicate that the *over the wall* approach often requires product redesign and a return to previous stages for corrections.

Process performance weaknesses found in the apparel *as is* environment are consistent with sequential manufacture problems. Cleetus (1992) and Menon (1992a) indicate that sequential manufacture is time-consumptive, expensive, requires product re-design, and is isolated from product manufacture. The *as is* environment has process performance weaknesses in time-to-market delay, excess cost, and reduced process quality. Reduced process quality from rework is a common occurrence in the *as is* environment. Process quality is reduced in the *as is* environment because design activities are isolated from product manufacture. For example, textile colorists noted that, for each

color developed, the dye piece sample (A2212) and generate color pigment (A233) processes had common rework cycles of three to ten times during a season. The findings document that the apparel associates developed an average of 35 colors seasonally for an SBU in the piece dye for garment process (A23). Combining rework cycles with the request to develop 35 colors, a colorist dyes and submits a range of 105 to 350 color tabs per season. This rework also contributes to time-to-market delays. Apparel associates identified time-to-market challenges as being related to weak communication between some of the design and product development areas. Some apparel associates indicated that major changes in an apparel line and the introduction of new products are not communicated to them on a timely basis. Late design communication created rework with pattern making, marker making, engineering, and manufacturing.

The significant findings of Phase Two are a proposed change in the traditional design and product development segment of apparel manufacture. The proposed change is the development of a CE apparel conceptual model that integrates apparel design with product development. Amacher et al. (1991) and Willett and Willett (1991) reported that apparel manufacture is a sequential process. The sequential process is confirmed in Phase One findings. The *to be* environment proposed a CE framework which changes apparel design and product development from a sequential process to a concurrent process. The concurrent design of products and related processes is part of the CE definition (Winner et al., 1988). Apparel associates choose many apparel activities to concurrently consider the design of product with their related processes. Concurrency was established when apparel associates ranked apparel activities as early, middle, or late within each of the CE conceptual statements. For example, apparel associates gave concurrent rankings to the DFLC-R apparel activities of develop colors and prints, identify raw materials, develop patterns, and develop prototypes. An example of the design of products with related

process within DFLC-R is for the multi-disciplinary design team to finalize colors and prints concurrently with color formulation, technical setup, and engrave screens.

The ranking of activities creates a *to be* design maturity curve. The key to design maturity is that a multi-disciplinary design team addresses early design issues (O'Brien & Smith, 1994). The design maturity approach is distinctly different from the *as is* environment findings. In the *to be* environment, apparel associates created multi-disciplinary design teams that address CE design issues on DFQ, DEFT, DFM, DFLC-I, DFLC-R, DFLC-M, and DFC. By using the design maturity approach, apparel associates consider a wider range of product design issues early in the product development process. The apparel associates selected apparel activities that crossed over the six separate *as is* design and product development functional areas earlier in the process.

Forty percent (i.e., 28) of the *to be* environment design activities from apparel line creation (A1) within DFQ, DFLC-R and DFLC-I moved to a later stage compared to their position in the *as is* environment. Fifty percent (i.e., 46) of the set production activities (A5) within DFQ, DFM, DFET, DFLC-I, DFLC-M, and DFC moved to an earlier stage compared to their position in the *as is* environment. The movement of activities supports Crow's (1992) opinion that considering manufacturability at the start is a DFM goal. The movement of apparel activities to earlier stages indicates that purchasing (A51), quality assurance (A52), and engineering (A53) activities could be made at an earlier stage in the product development process. Manufacturability considerations (i.e., produce samples [A6]) such as evaluating garments for machine efficiency and automation adaptability are late activities in the *as is* environment (i.e., A611, A612). Forty-six percent (i.e., 12 activities) of the *to be* environment manufacturability considerations moved to earlier stages than their positions in the *as is* environment. The *to be* sample production (A6) apparel activities that moved to an earlier stage are for garment sample evaluation.

The findings present a CE conceptual model that contributes to CE literature. Schmitz and Desa (1992) contend that CE is criticized for not having a widely accepted framework. The present study's CE apparel model foundation and structure have application to apparel manufacture. The formation of the researcher's CE apparel model development is consistent with Strauss and Corbin's (1990) grounded theory approach in which concepts are generated, systematically related, and conceptually linked. The base foundation for the CE apparel model is from the researcher's synthesis of published CE models (Crow, 1992; Hyeon et al. 1993; Schmitz & Desa, 1992; Sharon, 1992; Turino, 1992). The researcher used CE literature information to generate CE conceptual and CE operational statements (Blanchard et al., 1995; Boothroyd, 1992; Carter and Stilwell-Baker, 1992; Carver & Bloom, 1991; Crow, 1992; Duffey & Rosen, 1994; Ehresman et al. 1991; Maddux & Souder, 1993; Menon, 1992a; Shina, 1991; Syan, 1994). The use of CE conceptual statements and CE operational statements creates a CE framework that is grounded in CE literature and systematically organizes information for the *to be* $IDEF_0$ model. The grouping of apparel activities into conceptual categories comes from questionnaires given to focus groups of apparel associates. The reorganization of apparel activities creates linkages and a new structure for apparel activity sequencing.

Limitations

The present study is an interpretive qualitative research design using a case study approach and has limited external validity (i.e., generalizability). In the present study, the case study approach is not designed to be generalizable to a large population. Instead, it is designed to provide a benchmark for further study of CE in apparel manufacture.

Phase Two research is a proposed *to be* environment. Limitations of the present study's research methods include nonimplementation of the *to be* environment and

apparel associates' limited awareness of enabling technology. The apparel associates did not implement CE during the study; rather, the study proposed an integrated apparel product development process. The apparel associates used their professional expertise from the *as is* environment to create and evaluate the *to be* environment. For example, the conclusions of concurrency are based on ranking of timing, not actual process implementation. The *to be* environment findings that reorganized apparel activities and identified potential process performance improvement may not be valid until they are actually implemented in another study.

During data analysis, the researcher discovered some weaknesses in the enabling technology questionnaire due to sample size and apparel associates' limited knowledge of enabling technology. Many apparel activities did not have a level of frequencies to meet the pre-established cut off acceptance rate for enabling technology. A follow-up study on enabling technology use should confirm the present study's enabling technology findings.

Recommendations for Further Research

The present study is adaptable for further academic clothing and textile research, and applicable for use in the apparel industry. The *as is* environment findings, diagrammed on $IDEF_0$ charts, can be a foundation for many additional studies. The *as is* environment is divided into six major functional areas: create apparel line (A1), develop colors and prints (A2), implement fabric design and special operations (A3), create garment pattern and prototype (A4), set production specifications (A5), and produce samples (A6). A proposed quantitative study could research the separate functional areas to evaluate representation of functional activities, inputs, controls, outputs, and mechanisms to a stratified random sample. A suggested qualitative study on the *as is*

environment could evaluate another apparel manufacturer's *as is* environment using the present study's Phase One findings as a benchmark.

A proposed qualitative research study could use the *to be* environment as a foundation for case study with an apparel manufacture to implement CE. The *to be* environment could be implemented using test and control groups in which a researcher could compare multiple strategic business units. The test groups would be experimental multi-disciplinary design teams that would implement the concurrent apparel activities represented on the present study's *to be* $IDEF_0$ diagrams.

The questionnaires developed in the present study on multi-disciplinary design team and enabling technology could be used for a quantitative study. The questionnaires could be given to a random sample of apparel manufacturers. The findings from the proposed study could be used to verify and refine the present study's *to be* environment findings.

An in-progress dissertation at the University of Nottingham is surveying CE product development performance measures for multiple manufacturing industries, including apparel manufacture (H. Driva, personal communication, October 1996). A future study could use Driva's study as a foundation to quantitatively measure apparel manufacturers' process performance. The apparel manufacturing research study could be developed that operationalizes and compares time-to-market, excess cost, and process quality performance measures. For time-to-market, a researcher could conduct a longitudinal study over several apparel seasons by measuring actual time with the product development calendar when operating in the *as is* and *to be* environments. A researcher would first operationalize how multiple apparel manufacturers define excess cost, time-to-market delay, and process quality. The *to be* environment potential process performance on time-to-market delays, excess cost, and decreased process quality could be studied

using computer simulation. Using computer simulation, a researcher could evaluate excess costs using an apparel manufacturer's *as is* environment cost records and then propose ways to eliminate or reduce excess costs.

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Appendix A

Published Dissertation Abstract and Article

A-1 Applicability of the Engineering Design Process Theory in the Apparel Design Process

Manuscript Title: Applicability of the Engineering Design Process Theory in the Apparel Design Process

Submission to: Clothing and Textiles Research Journal
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Abstract

An effective apparel design process is key to the successful launch of an apparel product. Application of engineering design process theory, the foundation of the design process, may enhance understanding of the apparel design process. Goals of this research were to: (a) interpret actions and decisions made during the apparel design process, (b) determine whether the specific stages of engineering design process theory were used by apparel designers and merchandisers, and (c) determine applicability of engineering design process theory to apparel design. The research method was interpretive qualitative research employing triangulated methods of long interview and observation. Interview questions focused on actions and decisions made during the apparel design process. Inter-rater reliability and respondent validation were used to increase research reliability. Results showed that there is a systematic building block process to designing apparel lines and a direct relationship between engineering design process theory and process steps used by apparel design associates.

Key Words: Design, Process, Development, Line Plan

A-2 Interpretative Examination of Concurrent Engineering Constructs for Apparel Manufacture

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ABSTRACT: CE components are recognized as design for manufacturability, quality, cost, enabling technology, and the life cycle encompassing inspectability, reliability and maintainability. The research goals were to determine whether CE constructs are directly transferable to apparel manufacture and whether apparel manufacturing information adds a dimension to CE constructs. A qualitative study was conducted involving product development respondents from multiple independent apparel manufacturers. Respondents evaluated use of CE constructs in their firms for the 'as is' environment. The results showed that CE constructs are directly transferable to apparel manufacture. Respondents selected CE constructs that indicated apparel manufacturing uniqueness was dealt with through specific product manufacture decisions.

BACKGROUND

Peters [1] (p. 650) defines fashion as the "engine of progress", and successful companies must adopt fashion strategies in response to quickly changing product lines. Much of the published concurrent engineering (CE) research has focused on hard materials. The question remains that in apparel manufacture (i.e., fashion), with ever changing markets, can CE information be integrated. Two questions arise: (a) are CE constructs directly transferable to apparel manufacture and (b) can apparel manufacturing information add another dimension to CE constructs? Transferability of CE constructs is challenged by apparel manufacturer uniqueness: flexible raw material, limitations on large production runs, limitations of automated equipment, short product life cycles, shifting consumer demand, and seasonality of product lines [2].

CE focuses on integrating design decisions to determine how a product is used, made, maintained and disposed [3]. For an enterprise to accomplish these goals, CE is broken down into component parts [4]. While CE components have not been formally documented [5], generic CE components are generally recognized as: design for manufacturability (DFM), quality (DFQ), cost (DFC), enabling technology (DFET), and the life cycle (DFLC), encompassing inspectability, reliability and maintainability (see figure 1) [4, 6].

DATA COLLECTION

A qualitative case study approach was used to conduct the study. This approach was desired to establish a baseline for the 'as is' environment for the use of CE for apparel manufacture. Studying the 'as is' environment provides a good basis in identifying non-value added functions and provides a good picture of where the enterprise currently is. Assessing results provides a road map for creating a successful CE environment [5, 7].

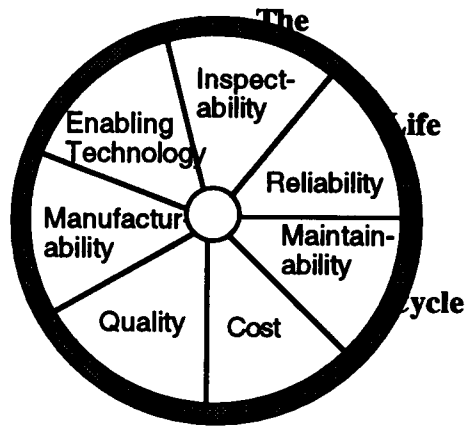


Figure 1. CE components. (Adapted from [4, 6].)

Instrument

A table of constructs, synthesized from published literature, was generated for generic CE components [4, 6, 8, 9, 10, 11, 12, 13]. CE components were divided into the following CE *design fors*: manufacturability, quality, cost, life cycle-reliability, life cycle-inspectability, life cycle-maintainability, and enabling technology. The CE components were further delineated into secondary constructs. The instrument only included constructs identified by multiple authors. (See Tables 1, 2, 3, 4.)

Company Profile and Sample

The sample was respondents from three independent apparel manufacturing companies, located in the Southeastern portion of the United States. Apparel manufacturing is a major industry in this region [2]. The companies' characteristics included multiple apparel merchandise classifications, multiple organizational structures, vertical manufacturing or non-vertical manufacturing, mid-price product line, and production in company-owned facilities. Two companies produced apparel products under their own label and one company produced products for a large domestic mail order company.

The data were collected Fall, 1995. Interviews included a cross section of personnel (N=23) from design, merchandising, pattern making, manufacturing, engineering, quality assurance and management. Subjects were surveyed on specific applications of CE constructs in apparel manufacture.

DATA ANALYSIS

The subjects were given the CE table of constructs and asked to indicate the current 'as is' environment for use of specific CE constructs. The responses were: (a) all of the time, (b) some of the time, (c) no wished the company used, (d) not applicable for apparel, or (e) don't know.

The respondents were asked to provide specific apparel examples of CE construct use. An interpretive examination determined whether selections were due to apparel uniqueness. The researchers evaluated comments to discern information learned from apparel manufacture.

RESULTS

Design for Manufacturability Use (DFM)

DFM ranked second overall in overall use in comparison with other CE components. Manufacturability considered at the start (1) was selected as being used all the time by majority (56%) of apparel associates. Specific comments were: designers and engineers evaluate designs during apparel line reviews, use historical knowledge, and design products sewable in domestically owned plants. DFM constructs that were used some of the time were: minimizing design variation (18) (70%), design for ease of fabrication (5) (56%), design for efficient joining and fastening (10) (56%), ergonomics and human factors requirements (12) (56%), producability designed into the product (2) (52%), simplifying and reducing the number of parts (3) (52%), and inspection or measurement at the source (15) (52%). Specific comments were: use of carry-over garments, standard trims, standard patterns, and standard manufacturing operations (see figure 2).

Design for Quality Use (DFQ)

DFQ was the overall category that had a majority of respondents selecting DFQ constructs used all the time. DFQ constructs, noted as used all the time, were using: acceptable tolerances (9) (83%), designing products to meet customer requirements (1) (65%), and designing products with an attractive look and feel (4) (65%). Specific respondent comments were: to try to be consumer and customer driven and use of consumer focus groups. DFQ constructs ranked close to the 50th percentile as being used all the time were: building in functionality into product (7) (48%), specific values for design parameters (8) (48%), and continuously improving product reliability performance to exceed customer expectations (12) (48%). Specific comments were the use of previous history and knowledge, +/- tolerances, specifications, and a 1 year product warrantee. DFQ constructs rated by the majority, as use some of the time, included: selecting high quality components (3) (52%), designing a robust product to counter or minimize potential variation in product manufacture (5) (52%), and minimizing the number of parts (11) (52%) (see figure 3).

TABLE 1

Design for Manufacturability Constructs

1. Manufacturability considered at start	10. Design for efficient joining and fastening
2. Producability designed into product	11. Design modular products
3. Simplify and reduce the number of parts	12. Ergonomics & human factors requirements
4. Standardizing parts and materials	13. Group technology
5. Design for ease of fabrication	14. Minimal handling
6. Mistake-proof product design & assembly	15. Inspection or measurement at the source
7. Parts orientation to minimize non-value added activities	16. Reducing machine or job set-up time
8. Minimize flexible parts and interconnections	17. Management systems & team organization
9. Design for ease of assembly	18. Minimizing design variation

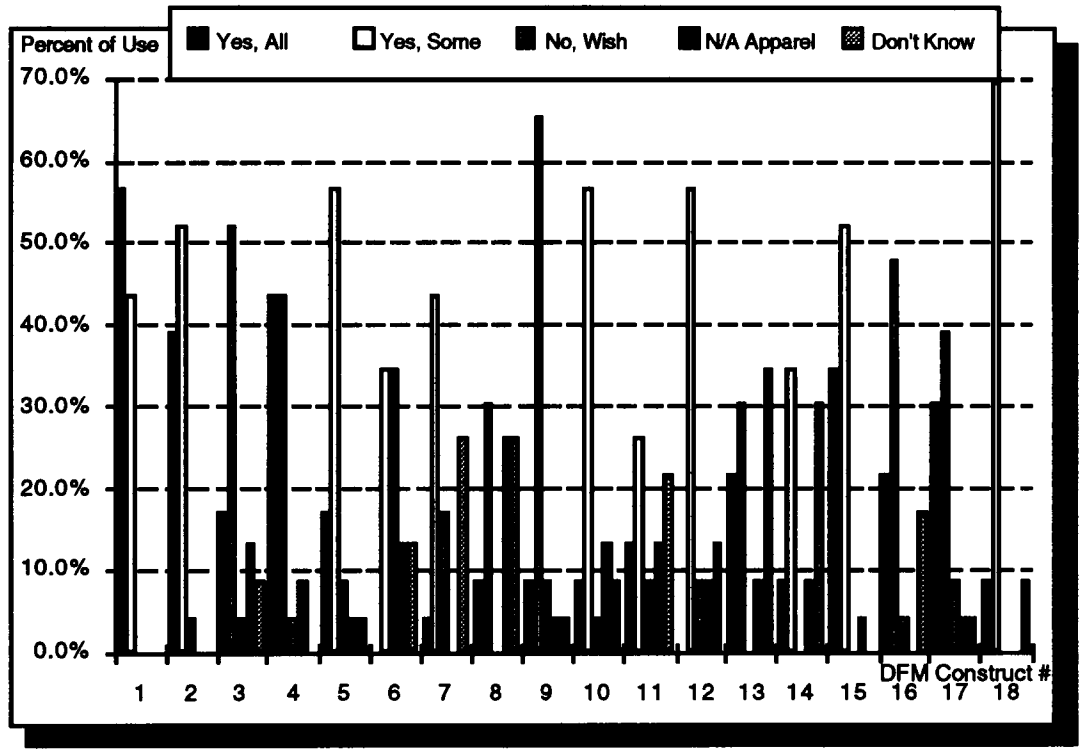


Figure 2. Design for manufacturability (DFM)

TABLE 2
Design for Quality Constructs

1. Design products for customer requirements	8. Specific values for design parameters
2. QFD/House of Quality	9. Acceptable tolerances
3. Selecting high quality components	10. Maximizing average part quality level
4. Design products with attractive look & feel	11. Minimizing the number of parts
5. Designing a robust product to counter or minimize potential manufacture variation	12. Continuously improving product reliability performance
6. Taguchi quality engineering	13. Benchmarking
7. Building in functionality of the product	

Design for Life Cycle Use: Inspectability, Reliability and Maintainability (DFLC)

Apparel associates indicated that DFLC inspectability, reliability, and maintainability were least used CE components. Many DFLC constructs did not have strong categorical selections. Within DFLC-inspectability, the specification of product parameters (3) was used all the time by 74%. DFLC-inspectability was accomplished through review meetings and specification sheets.

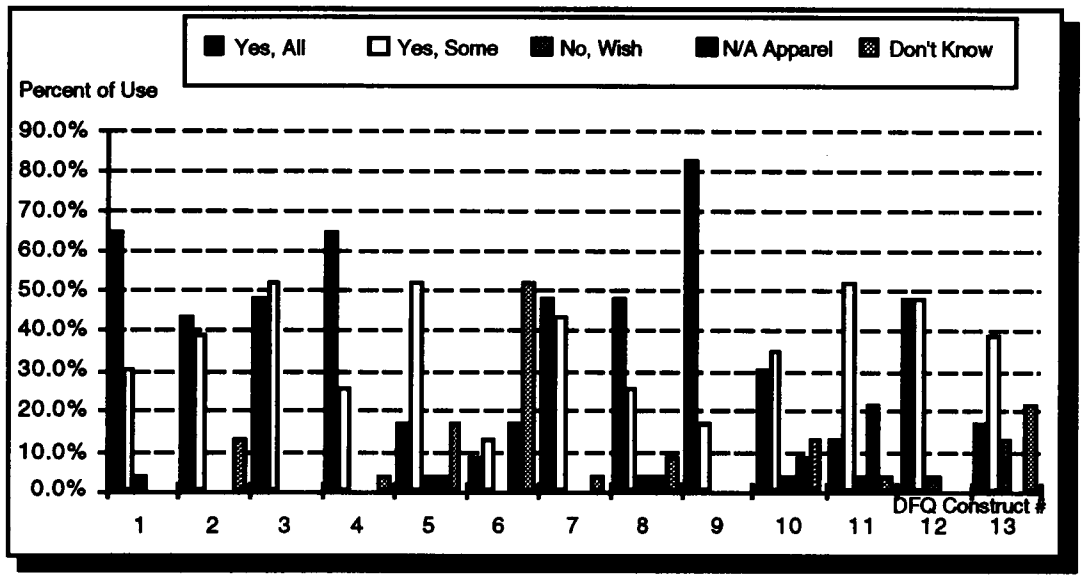


Figure 3. Design for quality (DFQ)

Automated equipment compatibility (4) (56%) and early quality assurance involvement (1) (52%) were selected as used some of the time. Quality assurance was involved with testing fabric and new apparel models. Approximately 35%-40% of respondents were not familiar with geometric dimensioning and tolerancing (2), built-in test diagnostic capability (5), and use of standard connections (6) (see figure 4).

A strong DFLC-Reliability construct was use of vendor partner relationships (5); being used either all the time (52%) or some of the time (48%). Close to the 50th percentile as being used some of the time was reliability engineers involved with design (48%) (2) through apparel line reviews and evaluating new fabrics and garment components. Many respondents were not familiar with Taguchi quality engineering (74%) (4) and computer-aided-engineering (CAE) tools to test (3) (52%). Designing, building prototypes and testing iterations (1) had strong use with 43% selecting all the time and 43% selecting some of the time (see figure 5).

DFLC-Maintainability did not have strong categorical trends. Thirty to 40% of respondents noted that modular design replacement (3), analyzing the mean time to replace (5), and using available, inexpensive parts (4) were not applicable for apparel. Designing products for easy maintenance, repair and replacement (1) had some use (43%) (see figure 6).

Design for Cost Use (DFC)

Target cost (1) was strongly used (78%) all the time in the DFC category. Target cost comments were used internally through the use of calculating first costs and market knowledge. Cost targets were tracked through the use of a line development calendar (see figure 7).

TABLE 3
Design for Life Cycle Constructs: Inspectability, Reliability and Maintainability

Design for Life Cycle- Inspectability (DFLC-I) Constructs	
1. Early involvement of quality assurance	5. Built-in test diagnostic capability
2. Geometric dimensioning & tolerancing	6. Standard connections
3. Specification of product parameters	7. Use standard test instruments to test
4. Automated equipment compatibility	
Design for Life Cycle – Reliability Constructs	
1. Design, build prototypes & test iterations	4. Taguchi quality engineering
2. Reliability engineers involved in design	5. Vendor/partner relationships
3. Computer-Aided Engineering tools to test	6. Proven standard parts
Design for Life Cycle – Maintainability Constructs	
1. Design products for maintenance & repair	4. Use available, inexpensive parts
2. Trade-off considerations	5. Analyzing mean time to replace (MTTR)
3. Modular design replacement	

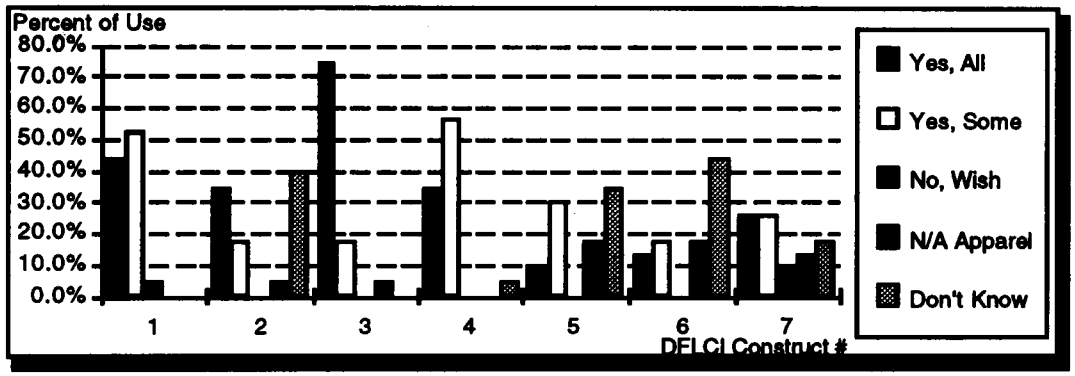


Figure 4. Design for life cycle-inspectability (DFLC-I)

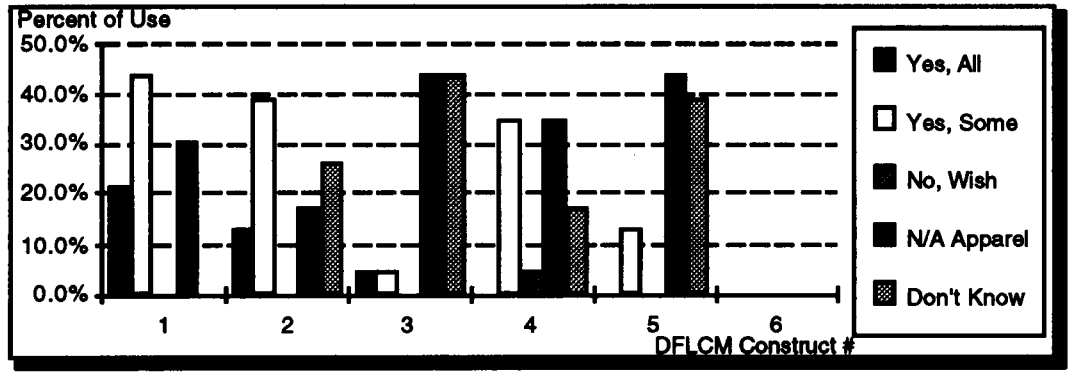


Figure 5. Design for life cycle-reliability (DFLC-R)

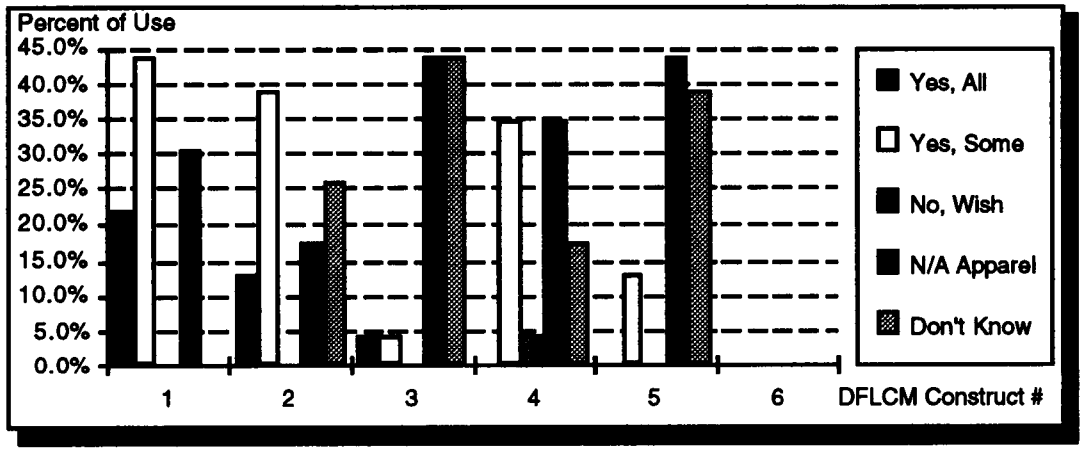


Figure 6. Design for life cycle-maintainability

TABLE 4
Design for Cost Constructs

1. Target costs for products	3. Life-cycle costing
2. A tracking system that monitors cost targets	

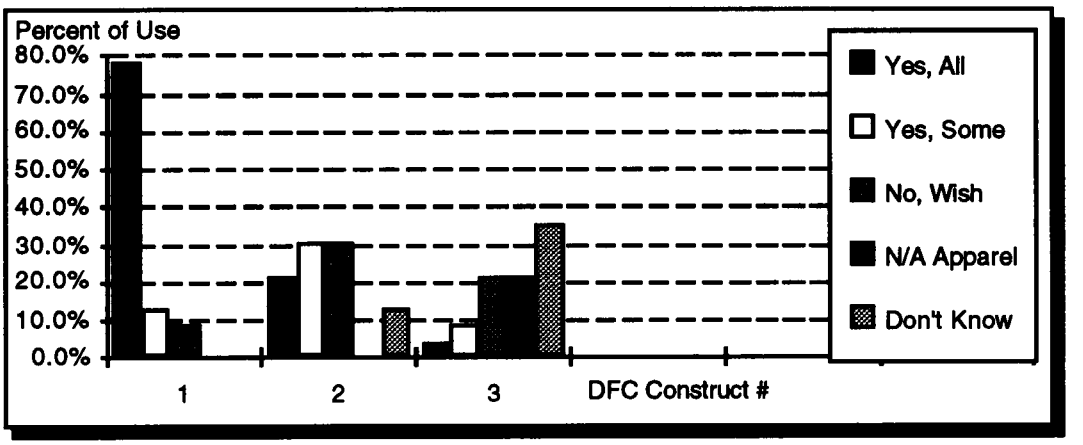


Figure 7. Design for cost

Design for Enabling Technology Use: Digital Process Models, Process Design and Data Interchange (DFET)

The strongest DFET – Digital constructs that were selected as used some of the time were: storing information in a logical, consistent, non redundant and reusable manner (2) (65%) and avoiding paper drawings (5) (52%). Specific comments related to use of CAD, history and Karat. (Karat is an on-line computer program to track and cost apparel.) (see figure 8.) In DFET – Process design, process plans defining how products are manufactured (2) was selected by a majority (61%) as being used all the time. Electronic data interchange (6) was selected as used some of the time (52%). Engineering was responsible for process design that included garment sequencing and plant layout for product machine and operation balancing. Tooling was set up for required parts (see figure 9).

TABLE 5
Design for Enabling Technology (DFET): Digital Product Models

1. Optimize design information (digital model)	5. Avoid paper drawings
2. Store information in logical, consistent, non redundant and reusable manner	6. 2D CAD or 3D CAD systems
3. Accumulate repeatable design knowledge	7. CAD solid modeling
4. Available digital product model data	8. CAD feature based representation

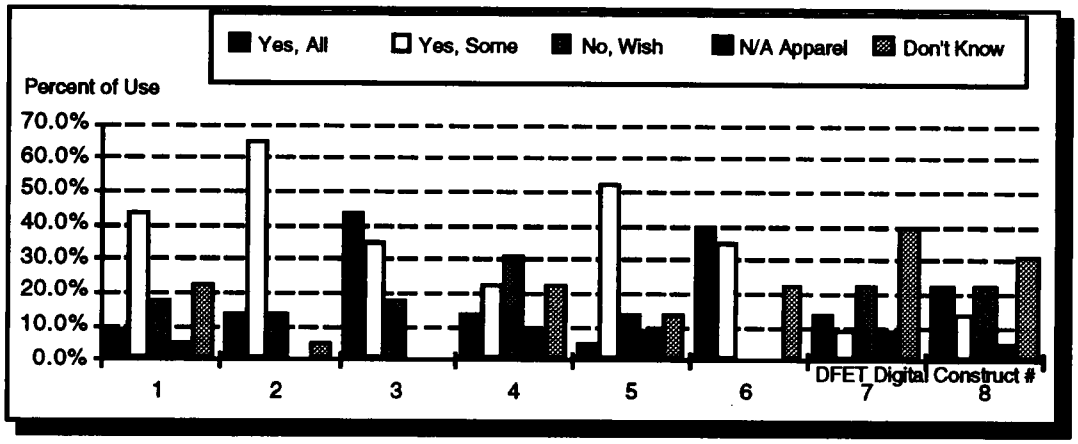


Figure 8. Design for enabling technology: Digital product models

TABLE 6
Design for Enabling Technology: Process Design and Data Interchange

Process Design	*Data Interchange*
1. Specify production equipment layout	5. Digital product data extends externally
2. Process plans defining product mfg.	6. Electronic data interchange
3. Parts and assembly programming	7. Product Data Exchange using STEP
4. Tool and fixture design	

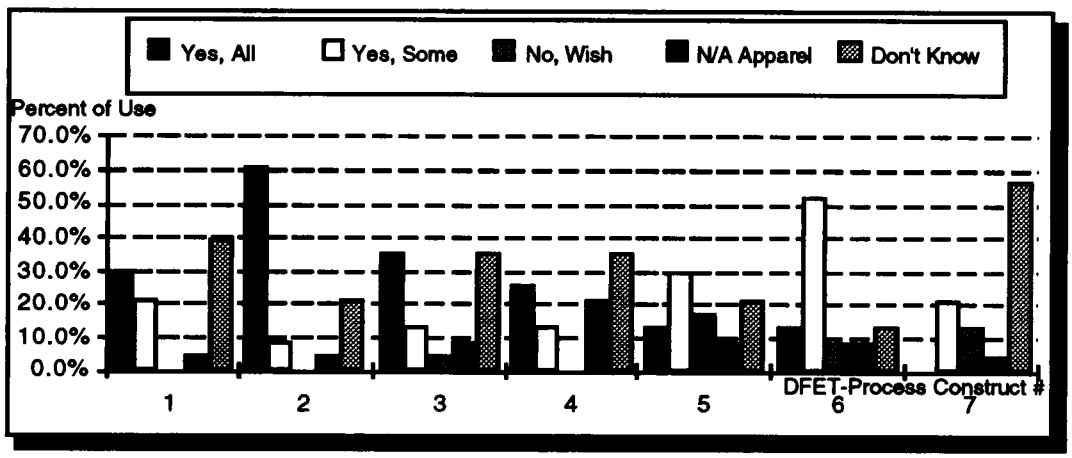


Figure 9. Design for enabling technology: Process design and data interchange

DISCUSSION

The uniqueness of apparel manufacture through automated equipment limitations, raw material, large production run limitations, short product life cycles, and shifting consumer demand, as noted by [2], were addressed by the selections that respondents made. Many respondents noted that a design consideration was automation compatibility. Respondents

addressed flexible material by designing for ease of fabrication, ease of assembly, efficient joining and efficient fastening. Respondents indicated that limitations of large production runs and short product life cycles were controlled by having specific design and product parameters and standardized parts and materials to minimize design variation. Respondents addressed shifting consumer demand through the selection of continuously improving product reliability performance, vendor partner relationships, and designing products with an attractive look and feel to meet customer requirements.

CE constructs transferable for apparel use are DFM, DFQ, DFC and DFET. Very few CE constructs were rated as not applicable for apparel manufacture. DFLC was the weakest area for the 'as is' environment. This finding could be caused by respondent unfamiliarity with DFLC terminology.

Additional research is needed surveying CE constructs for use in a variety of industries. The results of this research could provide a comparison baseline of apparel respondent selection with other industry sectors. Additional research using a national sample of apparel manufactures, would enhance this research.

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Appendix B

Research Relationships with People and Companies

B-1 Human Subjects Agreement

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: A Concurrent Engineering Framework for Apparel Manufacture

Principal Investigator: Cynthia Lee Regan

THE PURPOSE OF THIS RESEARCH PROJECT

You are invited to participate in a research study about an improved apparel design and product development process for apparel manufacture. The improved process is based on the concurrent engineering process; currently not used by the apparel industry. This study involves experimentation for the purpose of developing a framework that will map the decisions made during the current product development process and create a concurrent engineering framework for apparel manufacture.

The total sample for all companies is:

Title	Number to be Interviewed	Title	Number to be Interviewed
Costing Individuals	3	R & D personnel	2
Designer Associates	4	Merchandisers	6
Designers	6	Pattern Makers	3
Graders	3	Piece Good Purchasers	2
Industrial Engineers	6	Plant Managers	3
Marker Makers	2	Sample Makers	3
Textile Printers	3	Textile Colorist/Design	4

PROCEDURES

The procedures to be used in this research are observations and structured interviews with individuals and groups. The specific procedures are for the researcher to:

1. Interview and observe design and product development individuals. Each individual is audio taped.
2. Transcribe audio tapes.
3. Draw a model of the time and the decisions of sections of the current product development process and an apparel concurrent engineering model.
4. Distribute the model to the interviewee.
5. Review the model critique, completed by the interviewee.
6. Revise the drawn model.

The conditions required for you to participate in this project are in the corporate office and individual offices. Time for interviews will be during work hours and scheduled by supervisors. You will be asked to spend time reviewing and evaluating the drawn model.

There are no possible risks or discomfort to you as a participant in this study

BENEFITS OF THIS PROJECT

Your participation in the project will provide the following information that may be helpful.

1. The company gains the researcher's expertise to form an improved method of apparel design and product development.
2. There is no cost to the company (except time).
3. The end result will be a model of concurrent engineering tailored specifically to the apparel manufacture.
4. The company will be the first to have the Apparel Concurrent Engineering process improvement model.
5. The company will receive a copy of the Dissertation.

No guarantee of benefits has been made to encourage you to participate. The model developed is exploratory and has not been previously tested. Refinement of the finished model may be needed. The concurrent engineering framework is a process model and will not be implemented as part of the Dissertation. If desired, you will receive an executive summary of the research when completed.

EXTENT OF ANONYMITY AND CONFIDENTIALITY

1. The results of this study will be kept confidential. Any proprietary information, that comes in contact with the researcher, will not be published.
2. The subjects will not be identified directly or through identifiers with the information.
3. An intellectual properties copyright may be obtained by the researcher and Virginia Polytechnic Institute and State University. All rights belong to the researcher and Virginia Tech.
4. As required by the University, a confidentially agreement has been signed by the company stating that the data will be used for evaluation purposes only.
5. The Dissertation is a public document.
6. The researcher will publish research from the Dissertation. This will be written in a non proprietary manner, and if desired, data will be cleared with the appropriate manager, before publication.

Interviews and observations will be audio recorded. These tapes will only be reviewed by Ms. Cynthia Regan (principal investigator), Dr. Doris Kincade (Ph.D. advisor), and Dr. Ralph Badinelli (Ph.D. committee member). The tapes will be destroyed in December 1996, upon completion of the Dissertation.

SUBJECT RESPONSIBILITIES

I know of no reason I can not participate in this study. I am willing to be interviewed and/or observed by the researcher.

SUBJECT'S PERMISSION

I have read and understand the informed consent and conditions of this project. I have had all of my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project

If I participate, I may withdrawal at any time without penalty. I agree to abide by the rules of this project. Should I have any questions about this research or its conduct, I will contact:

Cynthia L. Regan
Principal Investigator
(540)552-7552

Dr. Doris Kincade
Ph.D. Chair
(540)231-7637

Dr. Ernest R. Stout, Chair
IRB Research Division
(540)231-9359

Signed

_____ Date _____

B-2 Company Responsibilities

Advantages and Expectations as a Partner with the Dissertation Project

Advantages

1. The company gains the researcher's expertise, pulled together from a variety of disciplines, to form an improved method of design and product development.
2. There is no cost to the company (except time).
3. The end result will be a model of concurrent engineering tailored specifically to the apparel industry.
4. You will be the first to have this Concurrent Engineering process improvement model.
5. You will receive a copy of the Dissertation.
6. You have the right to implement this Concurrent Engineering model, if desired, within your own individual company.
7. If desired, the researcher will sign a confidentially statement assuring the company that any proprietary information, that the researcher comes in contact with, will not be published.

Expectations

1. An intellectual properties copyright will be obtained by the researcher and Virginia Polytechnic Institute and State University. All rights belong to the researcher and Virginia Tech. As required by the University, a confidentially agreement needs to be signed by the company stating that the data will be used for evaluation purposes.
2. The model developed is exploratory and has not been previously tested. Refinement of the finished model should be expected.
3. The concurrent engineering is a process model that is not actually put into action.
4. The Dissertation is a public document.
5. The researcher will publish research from the Dissertation. This will be written in a non proprietary manner, and if desired, data will be cleared with your company before publication.

Appendix C

$IDEF_0$ Glossary and Outlines

C-1 $IDEF_0$ Glossary of Apparel Associates

Mechanisms-People	Specific Staff Titles	Mechanisms-People	Specific Staff Titles
Consumer/ Customer	Consumer focus groups	Merchandise Services staff	CAD Artist
	Key Account Retail Buyers		Merchandise Services Director
Design staff	Designer	Operations staff	Fabric Buyer
	Design Associate		Operations
Engineering staff	Cost Engineer	Outside Contract staff	Freelance Artist
	Product Engineer		Contractor
	Specification Writer	R & D staff	R & D Manager
			R & D Assistant
Management	President	Sales and Marketing staff	Marketing Services
	VP Finance		Sales Representatives
	VP Product Line		
	VP Sales	Service Support staff	Marker Making
Manufacturing staff	Assembly Operator		Pattern staff
	Assembly Supervisor		Prototyping staff
	Division Engineer		QA staff
	Plant Engineer	Textile staff	Design Room Manager
	Plant Manager		Textile Account Representative
	Production Scheduler		Textile Artist
	Sample Coordinator		Textile Color staff
Merchandising staff	Fashion Director		Textile Engraving
	Forecaster		Textile Finishing staff
	Merchandise Associate		Textile Plant Manager
	Merchandiser		Textile Printers
			Textile Strike-off
			Textile QA staff

$IDEF_0$ Supplement

C-2 $IDEF_0$ Functional Activity Notecards

$IDEF_0$ Notecards for Current Design and Product Development Process

( ) Is an IDEF symbol which indicates that an input, control or output are not indicated at lower level drawings.

A0 Notecard for "Design & Develop Apparel Product"

Apparel companies have different titles for design and product development individuals. The titles listed are generic and represent the functional responsibility. See glossary for position descriptions.

The design and product development activities have been represented for cut and sewn products and full fashion knitting products. The majority of the activities represented pertain to cut and sewn products. As full fashion knitting is a niche product, only selected model activities pertain to the design and manufacture of the product.

Some apparel companies use computers and automated equipment throughout design and product development while other companies perform the same activity manually. Both computer and manual methods are represented in the model.

A3 Notecard for "Implement Fabric Design & Special Operations"

The term *fabric* refers to raw materials needed to create fabric, from an apparel manufacturers perspective. A garment-dyed style would start at the yarn stage, whereas a printed fabric garment would start at the griege good woven or knit fabric stage. Depending on the desired finished garment, one can substitute the term *fabric* to be *yarn*.

A4 Notecard for "Create Garment Pattern & Prototype"

Computers, computer equipment and software are commonly used for pattern development; however, patterns may still be made manually. Manual pattern making does not require computer equipment.

A11 Notecard for "Develop Design & Business Goals"

Product definition and product line strategy include apparel associates consideration of line distinctiveness, consumer appeal, design validity, consumer acceptance, sellable product definition, trend definition, core market definition, consumer definition, product category offering, fashion direction, competitive advantage strategy, and providing product value.

A12 Notecard for "Create Design Objectives: Define Problem"

Environmental scan includes key item definition, retail sales trends, garment category trends, and market information on color, themes, fabrics and silhouettes.

A1131 Notecard for "Shop Foreign Markets"

This activity takes place 6 months-1 year in advance of the on-sale date. The written trend report includes popular trends, new product identification, needle (construction quality) and sketches. The apparel associates begin formulation of the line plan.

A1132 Notecard for "Shop Domestic Markets"

Key markets are generally accepted as New York and Los Angeles. Travel to other markets (e.g., Atlanta, Chicago) varies by the apparel product line offered.

The domestic market trend report includes market direction, environment, and demand. The report summarizes wholesale colors, themes, popular silhouettes, fabrics, and retail store merchandising.

A125 Notecard for "Identify Fabric Type(s)"

Textile vendors tend to limit production to certain fabric or print types. At vendor presentations, textile representatives describe new fabric lines and existing fabric lines for fabric weight, finish, and feel. The base fabric cost may be pre-established or negotiated later.

A1421 Notecard for "Select Colors"

Cost can be dependent on dyestuff composition. Textile colorists state that direct dyes are less expensive than reactive dyes; however, certain colors desired dictate the dyestuffs which are needed.

A152 Notecard for "Finalize Color Palette"

A color standard is a color that apparel manufacturers want textile dyers to match. Color standard submits vary by company. Some color standard submissions are on cards in fabric type desired. Other color submits include yarns, twigs and small fabric pieces. A color library is a color palette with established dye recipes from a specific textile dyer and was used in a prior season.

A154 Notecard for "Create Concept Boards"

Preline meetings vary by company organization. Some apparel manufactures preline early with color, fabric, and theme ideas (no silhouettes). Other companies preline later when silhouettes have been determined.

A1533 Notecard for "Finalize Fabric Ideas"

Fabric development may differ for apparel manufactures. Some apparel manufactures do print development in-house with their own CAD department. Other companies develop fabrics out-of-house with textile vendors.

A15331 Notecard for "Create Painting (manual or CAD)"

Textile print ideas are painted either manually with paper, brush, and paint or through the use of CAD. CAD drawings are being accepted as the recognized media form.

A1563 Notecard for "Evaluate Garment Bodies"

Evaluation criteria for garment bodies are: single style determination, multi-pack (set) style determination, coordination fashion injection, and reorderable styles. The associates also analyze the feasibility of garment make/construction, with company quality standards, adjust bodies to meet construction requirements, and garment construction comparison with the competition. The final judgment criteria is whether the garment meets minimum margin requirements.

A1611 Notecard for "Show Concepts to Accounts"

Apparel associates show concepts to accounts for early identification of best selling styles/weak selling styles. Prelining is necessary for future season information, reorderable items refinement, the line revised, and SKU quantity (dozens) determined.

A1641 Notecard for "Conduct Concept Meeting"

At concept meetings, apparel associates present an strategic business unit's line. Line parameters include numeric estimations of colors, prints, constructions, new styles, existing styles, special operations, and special labor. Styles are pre-ranked. Problems with not adhering to calendar goals are identified.

A1642 Notecard for "Freeze the Line"

Freeze the line refers to the design maturity. Design releases the apparel line to product development. Final line parameters include garment sell-through numbers (existing bodies and new bodies, total dozens per stock keeping unit). A category plan includes SBU breakdown for manufacturing style quantities. Potential manufacturing problems are identified during line freeze meetings. The problems are related to new piece goods, findings, trim, machines needed, and patterns.

A2321 Notecard for "Review Print Package"

A new practice in the apparel industry is to send an electronic file to the textile print engraver. The file may be sent by modem, floppy disk, or optical disk. Many apparel manufactures still send original manual paintings for art submission.

A2331 Notecard for "Refer to Color Library"

The customer order includes color name, order number, screen numbers, combination number and style number. The formula card includes the pattern, order, and color.

A2332 Notecard for "Generate Color Formulations"

Mesh size can be a constraint as the finer the mesh is, the lighter the dye color that is printed. Fabrication weave can be a constraint as it can be difficult to have consistent printing with different weaves (e.g., piqué texture). Desired print can be a constraint in adhering to quality standards. For example, a dark blotch background may not pass color crocking standards.

A3 Notecard for "Implement Fabric Design & Special Operations"

The term *fabric* refers to raw materials needed to create fabric, from an apparel manufacturer's perspective. A garment-dyed style would start at the yarn stage, whereas a printed fabric garment would start at the griege good woven or knit fabric stage. Depending on the desired finished garment, one can substitute the term *fabric* to be *yarn*..

A4 Notecard for "Create Garment Pattern & Prototype"

Computers, computer equipment, and software are commonly used for pattern development; however, patterns may still be made manually. Manual pattern making does not require computer equipment.

A3121 Notecard for "Scan Original Art"

When fabric engravers scan original art, files can be saved in 8-bit or 24-bit block format. The 24-bit format allow more color separation capability. Some apparel customers submit files in an electronic format (e.g., floppy disk). This eliminates the need for scanning the art design.

A3132 Notecard for "Print Table Strikeoff"

Print Table strikeoff activity (A3142) and Print First Production Run activity (A3143) are interchangeable. A fabric printer usually performs only a table strikeoff process or a first production run, but generally not both.

A411 Notecard for "Evaluate & Measure Competitor Garment Fit"

Size standards may either be from a government size report from NIST, or from customer key account retailer size measurement recommendations.

A413 Notecard for "Establish Quality Standards for Garment"

Construction quality directs the types of seams, hems and stitching in pattern making.

A4121 Notecard for "Drape Fabric on Dress Form"

Fabric type dictates looseness or tightness of fit. Some special operations (e.g., laundering) require that extra ease be put into a garment. Pattern blocks are created manually or by CAD which is up to the Pattern Maker's preference.

A4231 Notecard for "Write Up Work Sheet"

The design request evaluation includes the Pattern Maker's decisions on whether a garment request will work using basic pattern block, what garment component and special operations are requested, and how to interpret the request into pattern instructions. Pattern interpretation includes decisions on, shrinkage allowance, pattern standards, pattern specifications, cut lengths collars, cuffs, binding, special instruction provisions, manufacturing specifications, clarification of garment design, and reference to previous designs.

A442 Notecard for "Sew Prototype"

The sew prototype functional activity is meant for cut and sew products only. Refer to activities A331 and A63 for full fashion knitting prototype and sample process.

A511 Notecard for "Evaluate & Specify Fabrics"

A sample fabric purchase order includes fabric name, overall width, selvage width, weight, fiber blend, fabric style number, color(s), color number, fabric price, required yardage quantities, date needed to send to manufacture location, sample delivery date, stock delivery date, pickup issue, date received, fabric standard approval, and number of screens (print only).

A5111 Notecard for "Identify Piece Goods"

Identification of piece goods is the initial contact between the fabric buying staff and textile vendors. The communication includes written and or communication on minimum buy quantities, sample delivery, new fabrics and carryover identification, fabric quantity estimate, yardage yield calculation (amount per style), and vendor availability notification.

A5131 Notecard for "Set Up Fabric Codes"

The fabric buying staff enter fabric information into the computer database system. The fabric information entered includes fabric codes, fabric price, specifications (i.e., screen, printing, prepare for finish charges), and weekly sample report update. The weekly sample report update includes sample yardage needed, fabric received, lot number receipt date, date ordered, date due, pick up number generated, and lot number.

A5133 Notecard for "Relay Fabric Reports"

A strikeoff approval includes the following considerations: print colors match coordinate garment, engraved screens match artwork, print detail approval, print repeat approval, print registration approval, print colors match and first production approval. A strikeoff rejection includes reasons for strikeoff rejection and identified print problems.

A5214 Notecard for "Test Textile Piece Goods"

The Quality Assurance Supervisor contacts the appropriate Merchandiser and Designer if piece goods fail textile tests. If a piece good lot fails, inferior piece goods are used for sample production due to time constraints. The textile vendor is contacted by the merchandiser to correct textile problems for full production.

A63 Notecard for "Full Fashion Knit Samples"

The full fashion knit process is unique. The pattern pieces are not cut out of fabric and sewn as in the majority of apparel manufacture. Rather, the pattern shapes (e.g., front, back, sleeves) are created in the knitting process. The measurement specifications are machine-dependent; a slight change in measurements can have a tremendous size change in garment pieces. The knitted pieces are assembled through looping (i.e., a specific stitch sewn with yarn rather than thread).

A641 Notecard for "Conduct In-process & Final Sample Inspection"

QA Auditors have a dual role of folding, pressing, pinning and trimming sample garments, and final inspection.

$IDEF_0$ Notecard for Integrated Apparel Product Development

Notecard for Integrated Apparel Product Development Process

A0 Notecard for "Create Integrated Apparel Product Development"

C*: Represents all of the Controls.
- C1 Prior problem avoidance
- C2 Budget
- C3 Calendar adherence
- C4 Company mission statement
- C5 Dedicated facilities
- C6 Equipment constraints
- C7 Margin requirements
- C8 Quality standards
- C9 Raw material constraints
- C10 SBU direction

O*: Represents all of the Outputs
- O1 Line plan
- O2 Purchase order
- O3 Style description sheet
- O4 Garment sample
- O5 Sample approval
- O6 Production tooling and equipment order
- O7 Sales package

I*: Represents all of the Inputs
- I1 Apparel release date
- I2 Instructions
- I3 Machine attachments
- I4 Observation
- I5 Raw materials
- I6 Reports
- I7 Reference
- I8 Work kit

( ) Is an IDEF symbol which indicates that an input, control or output are not indicated at lower level drawings.

Cascading lines implies outputs are working together towards a common goal.

C-3 Current Design and Product Development Process

IDEF A0 Node Outline

IDEF$_0$ Node Tree Diagram for *As Is* Environment

A	0	Design and Develop Apparel Product
A	1	Create apparel line
A	11	Develop design & business goals
A	111	Determine minimum plan
A	112	Understand marketing concept
A	1121	Use company mission statement
A	1122	Conceptualize line for target market
A	1123	Use brand marketing strategy
A	113	Search environment for information
A	1131	Shop foreign markets
A	1132	Shop domestic markets
A	1133	Buy reference items
A	1134	Observe consumers
A	1135	Scan published literature
A	1136	Sketch reference items
A	12	Create design objectives: define problem
A	121	Define new season apparel line
A	122	Define & set theme direction
A	123	Identify carry-over colors & styles
A	124	Maintain basic line (core items)
A	125	Identify fabric type(s)
A	126	Identify garment component characteristics
A	13	Explore the problem
A	131	Determine strategy for reorderable core items
A	132	Determine strategy for directional fashion items
A	133	Evaluate color & style forecast
A	134	Evaluate fabric type & style
A	1341	Participate in textile concept meetings with vendors
A	1342	Evaluate textile vendor fabrics & prints
A	1343	Create theme concepts
A	135	Create ideas for new garment body styles
A	1351	Use reference library for fabric & silhouette
A	1352	Conduct classification analysis
A	1353	Evaluate previous season's best sellers
A	1354	Sketch designs
A	14	Search for alternatives
A	141	Select carry-over & reorderable garments
A	1411	Specify carry-over features for new season
A	1412	Evaluate reports
A	1413	Create carry-over garment ideas
A	1414	Create carry-over prototype
A	142	Merchandise the line

(table continues)

A	1421	Select colors
A	1422	Explore print ideas
A	1423	Explore texture & fabric piecing ideas
A	1424	Explore new fabrics
A	143	Develop new prototype styles
A	15	Evaluate & make decisions
A	151	Merchandise the line (draft cut)
A	152	Finalize color palette
A	1521	Refer to color standardization notebook
A	1522	Evaluate & narrow colors
A	1523	Finalize colors
A	153	Finalize fabric prints & textures
A	1531	Use fabric library
A	1532	Communicate with textile vendor
A	1533	Finalize fabric ideas
A	15331	Create painting (manual or CAD)
A	15332	Refine painting (manual or CAD)
A	15333	Perfect coloration (manual or CAD)
A	15334	Create final painting – CAD drawing
A	15335	Approve paintings – CAD drawings
A	154	Create concept boards
A	155	Design carry-over garments (bodies)
A	156	Design new garment styles (bodies)
A	1561	Scan reference item
A	1562	Sketch garment bodies
A	1563	Evaluate garment bodies
A	1564	Revise garment bodies for seasonal line
A	16	Specify & communicate solution
A	161	Decide optimum garment solution
A	1611	Show concepts to accounts
A	1612	Identify best styles
A	1613	Identify questionable bodies
A	1614	Select final fabrics (prints, solids, textures)
A	1615	Project fabric & trim
A	1616	Calculate first cost
A	162	Review garment styling construction
A	163	Disseminate line sheets (manual or electronic)
A	1631	Complete line sheets
A	1632	Enter line sheets into database
A	1633	Disseminate line sheets (manual or electronic)
A	1634	Develop sales sheets
A	16341	Create CAD visual
A	16342	Determine category plan
A	16343	Write sales description
A	164	Communicate seasonal plan
A	1641	Conduct concept meeting
A	1642	Freeze the line
A	1643	Conduct line review sales forecast
A	165	Present line & best styles

(table continues)

A	2	Develop Colors & Prints
A	21	Implement color process
A	211	Send color standard to textile vendor
A	2111	Determine quality features
A	2112	Establish desired garment performance
A	2113	Set procedure for substandard fabric acceptance
A	212	Log color request
A	213	Compile color library
A	214	Compile color history
A	22	Implement color piece dye (yard goods)
A	221	Develop color for piece dye (yard goods)
A	2211	Log standard, send to colorist
A	2212	Dye pieced sample
A	22121	Check & use color library
A	22122	Evaluate color
A	22123	Create lab dip
A	22124	Match lab dip to color standard
A	22125	Approve color
A	22126	Write color formulation
A	2213	Evaluate color quality
A	22131	Evaluate problems in matching colors
A	22132	Evaluate color light quality
A	22133	Evaluate color repeatability
A	22134	Check sample color dyeing
A	22135	Evaluate run card for color repeatability
A	222	Prepare fabric for finish
A	2221	Prepare fabric for dye scour & bleach
A	2222	Slit fabric
A	2223	Tenter fabric
A	223	Approve fabric & colors
A	224	Evaluate piece good quality
A	23	Generate color printing process
A	231	Create technical setup
A	2311	Put print into repeat
A	2312	Style art design to meet customer price structure
A	2313	Create print package (design studio)
A	23131	Complete pattern identification sheet
A	23132	Complete color pitch sheet
A	23133	Complete pattern summary sheet
A	23134	Send package to engraver
A	2314	Submit print package to plant
A	232	Create technical setup (print plant)
A	2321	Review print package
A	2322	Determine order to pitch & color position
A	2323	Determine pattern step & repeat
A	233	Generate color pigment
A	2331	Refer to color library
A	2332	Generate color formulations

(table continues)

A	2333	Create color tabs
A	2334	Approve color tab
A	24	Implement piece dye for garments
A	241	Evaluate color request
A	242	Check color library
A	243	Create color recipe
A	244	Create dye for garment
A	2441	Run dye bath
A	2442	Rinse & adjust color
A	2443	Dry samples
A	2444	Evaluate color quality
A	2445	Approve color
A	2446	Write color formulation
A	25	Approve dyed color samples
A	251	Compare color submit to color standard
A	252	Approve color
A	253	Submit color card for production
A	3	Implement Fabric Design & Special Operations
A	31	Generate rotary print process
A	311	Engrave screens manual process
A	3111	Create pattern guide
A	3112	Scribe design
A	3113	Editing and modifying art for printing
A	3114	Create technique effects
A	3115	Separate colors
A	3116	Cut screens photo sensitive engraving
A	312	Engrave screens automatic process
A	3121	Scan original art
A	3122	Clean up color trash
A	3123	Edit, modify art for printing
A	3124	Separate colors
A	3125	Fill colors
A	3126	Cut screens laser engrave
A	313	Print sample fabric transfer print process
A	3131	Print pattern on paper
A	31311	Set up screens
A	31312	Draw color through strainer
A	31313	Pump color into screen
A	31314	Print transfer paper
A	3132	Print table strikeoff
A	3133	Print sample fabric
A	314	Print sample fabric rotary screen process
A	3141	Print table strikeoff
A	31411	Set up screen (first in sequence)
A	31412	Draw color through strainer
A	31413	Pump color into screen
A	31414	Print screens
A	31415	Finish table strikeoff

(table continues)

A	3142	Print first production run strikeoff
A	31421	Set up print machine
A	31422	Print leader cloth
A	31423	Print first production (internal approval)
A	31423	Submit fabric piece for customer approval
A	31424	Finish fabric
A	31424	Print & finish fabric
A	31425	Complete & ship fabric package
A	3143	Evaluate fabric quality
A	31431	Schedule strikeoff date
A	31432	Evaluate table strikeoff (print plant)
A	31433	Approve strikeoff
A	32	Create engineered fabric designs
A	321	Create engineered design ideas
A	322	Create engineered fabrics & garment
A	3221	Review design request with product category
A	3222	Create engineered prototype
A	3223	Calculate optimum specifications for garment
A	3224	Create mini plot, determine fabric utilization
A	3225	Check measurements
A	323	Nest pattern & write marker instructions
A	324	Review nested pattern
A	325	Create marker for engineering & check accuracy
A	33	Create knit developed fabrics
A	33	Create knit developed fabrics
A	331	Full fashion knitting
A	3311	Develop knitting specifications
A	33111	Develop full fashion knitting specifications
A	33112	Develop flat knitting specifications
A	33113	Communicate knitting requirements
A	33114	Write knitting manufacturing specifications
A	33121	Write specifications for machine
A	33122	Build chains
A	33123	Knit panel
A	33124	Evaluate stitch
A	33125	Evaluate knit piece shrinkage
A	3313	Knit flat knitted trim
A	3314	Put pieces in work in progress stage area
A	332	Knit textures circular knitting
A	3321	Discuss texture development
A	3322	Submit developed fabric order
A	3323	Approve fabric
A	3323	Communicate texture product development
A	3323	Create knit textures
A	3323	Determine textured fabric adjustments
A	34	Develop special operations & identify trim
A	34	Develop special operations & identify trim
A	341	Select trims & findings
A	3411	Run reports, input sample information
A	3412	Track fabric until plant receipt

(table continues)

A	3413	Determine specifications
A	3414	Verify specification correctness
A	3415	Write specific instructions
A	342	Create artwork for special operation
A	3421	Create design
A	3422	Create pattern guide
A	3423	Nest artwork
A	3424	Write & submit detail sheet instructions
A	3425	Send artwork package to manufacturing plant
A	343	Perform in-house special operation
A	3431	Draft embroidery
A	3432	Punch embroidery
A	3433	Set up embroidery machine
A	3434	Create mending
A	3435	Approve mending
A	344	Monitor outside special operations process
A	3441	Draft artwork
A	3442	Separate colors
A	3443	Shoot screens
A	3444	Pull cut sample pieces
A	3445	Implement screen printing
A	3446	Approve outside special operation
A	345	Perform outside special operation: laundering
A	3451	Pull garment samples
A	3452	Launder garment
A	3453	Run garment quality test
A	3454	Evaluate special operation quality
A	4	Create Garment Pattern & Prototype
A	41	Create basic pattern block
A	411	Evaluate & measure competitor garment fit
A	412	Create basic block pattern
A	4121	Drape fabric on dress form
A	4122	Create basic block
A	4123	Draw or digitize basic block into computer
A	4124	Assign pattern block grade rules
A	4125	Evaluate fit
A	4126	Readjust pattern
A	413	Establish quality standards for garment
A	414	Adjust garment dimensions
A	4141	Evaluate for aesthetics
A	4142	Evaluate for fit
A	4143	Remake basic block
A	4144	Add shrinkage for specific fabrics
A	4145	Adjust patterns for special operation pattern pieces
A	4146	Approve basic block fit
A	42	Create new styles bodies
A	421	Review style request
A	422	Determine pattern/special operation adjustment

(table continues)

A	4221	Evaluate single fabric patterns
A	4222	Evaluate multiple fabric patterns
A	4223	Evaluate special operation
A	423	Create first pattern
A	4231	Write up work sheet
A	4232	Create pattern
A	4233	Proof pattern measure & check specifications
A	424	Revise/adjust first pattern
A	425	Evaluate design efficiency
A	43	Create carry-over garments
A	431	Review style development request
A	432	Write up work sheet
A	433	Create new pattern from basic block
A	434	Proof pattern measure & check specifications
A	435	Revise/adjust first pattern
A	44	Request & develop prototypes
A	441	Give essentials to prototype sewing
A	442	Sew prototype
A	4421	Cut pattern layout
A	4422	Sew garment
A	4423	Prototype finishing
A	4424	Send prototype to special operations
A	443	Review prototype
A	4431	Check prototype
A	4432	Evaluate prototype: design assessment
A	4433	Assess prototype for fit
A	4434	Review prototype manufacturability
A	4435	Approve prototype
A	4436	Review prototype assessment sheets
A	444	Revise patterns & prototype
A	445	Make changes after prototype completion
A	45	Grade patterns & submit instructions
A	451	Develop grade rules & specifications
A	452	Grade patterns
A	453	Review nested plot
A	454	Calculate first cost markers
A	455	Submit pattern & marking instructions
A	456	Generate reports

A	5	Set Production Specifications
A	51	Purchase fabric & findings
A	511	Evaluate & specify fabrics
A	5111	Identify piece goods
A	5112	Identify trims & findings
A	5113	Verify fabric & trim specifications
A	5114	Assign fabric codes
A	512	Determine & purchase sample yardage quantity
A	5121	Negotiate sample fabric prices & cost assignment
A	5122	Calculate raw material prices

(table continues)

A	5123	Generate sample purchase order
A	5124	Finalize purchase
A	513	Review sample fabric report
A	5131	Set up fabric codes
A	5132	Generate fabric reports
A	5133	Relay fabric reports
A	52	Conduct fabric & garment QA process
A	521	Conduct fabric quality assurance
A	5211	Set company quality assurance standards
A	52111	Determine quality features
A	52112	Establish desired garment performance
A	52113	Set procedure for substandard fabric acceptance
A	5212	Adapt, maintain vendor performance certification
A	5213	Control, inspect griege goods
A	5214	Test textile piece goods
A	5215	Evaluate fabric problems
A	5216	Test yarn weight (FFK)
A	522	Conduct garment testing
A	5221	Inspect griege garment
A	5222	Evaluate garment appearance
A	5223	Evaluate garment sewability
A	5224	Conduct & evaluate wear tests & garment tests
A	5225	Analyze problems
A	5226	Communicate problems
A	523	Conduct trim quality assurance
A	53	Conduct engineering process
A	531	Conduct test cuts & piece goods test
A	5311	Request new fabric, trim, or sewing application
A	5312	Submit piece good test
A	5313	Sew trim, piece goods, test cut
A	5314	Evaluate sewability of fabric/trim
A	5315	Evaluate test cut new construction
A	532	Assign sample production
A	5321	Attain style/lot number
A	5322	Determine plant history
A	5323	Balance sample assignment
A	5324	Submit sample assignment to plant
A	533	Generate style development
A	5331	Review line sheets
A	5332	Update carry-over information
A	5333	Enter lot numbers into system
A	5334	Update new styles
A	534	Generate samples
A	5341	Create specifications & sample package
A	53411	Run reports, input sample information
A	53412	Track fabric until plant receipt
A	53413	Determining specifications
A	53414	Verify specification correctness
A	53415	Write specific instructions
A	5342	Determine & write routing

(table continues)

A	5343	Implement specification change
A	5344	Conduct costing
A	53441	Calculate regular cost
A	53442	Calculate sample direct & indirect costs
A	53443	Calculate margins
A	53444	Conduct retail pricing analysis
A	53445	Review cost sheets
A	53446	Price the line
A	5345	Track samples & special operations
A	535	Manage delay in production process
A	5351	Review line sheets
A	5352	Evaluate changes made to samples
A	5353	Evaluate changes made to production
A	5354	Generate & evaluate change orders
A	54	Create markers
A	541	Establish best fabric width
A	542	Check marking instructions
A	543	Create markers (single fabrics)
A	5431	Read instructions & refer to marker book
A	5432	Lay sample, costing marker
A	5433	Check marker & evaluate fabric utilization
A	5434	Approve marker
A	5435	Remake & recut marker
A	544	Create markers (multiple fabrics)
A	5441	Read instructions, refer to marker book
A	5442	Lay multiple fabric sample costing marker
A	5443	Check marker & evaluate fabric utilization
A	5444	Approve marker
A	5445	Remake & recut marker
A	545	Transfer marker
A	5451	Check marker
A	5452	Send sample marker to plants
A	5453	Issue cuts
A	6	Produce Samples
A	61	Evaluate garment construction(plant)
A	611	Review sample production for handling, quality & rates
A	6111	Evaluate garment for standard operations
A	6112	Evaluate garment for nonstandard operations
A	6113	Determine product affordability
A	612	Evaluate garment tooling & equipment
A	6121	Evaluate garment for automation adaptability
A	6122	Evaluate garment for equipment limitations
A	6123	Evaluate garments for machine efficiency
A	613	Evaluate cutting/sewing problems
A	614	Pattern/marker change request from manufacturing
A	62	Produce sewn samples
A	621	Review sample package
A	622	Track samples (plant level)

(table continues)

A	623	Manufacture samples
A	6231	Issue sample cuts (plant)
A	6232	Cut & bundle sample pieces
A	6233	Sew/assemble samples
A	63	Produce full fashion knit samples
A	631	Assemble prototype
A	632	Finish garment
A	633	Inspect garment
A	634	Conduct measurement dimensional analysis
A	635	Evaluate garment
A	64	Evaluate & ship samples
A	641	Conduct in-process & final sample inspection
A	6411	Conduct sample production audits
A	6412	Finish samples
A	6413	Conduct final sample inspection
A	642	Pack & ship samples
A	643	Evaluate sample appearance
A	644	Engineering evaluates sample construction
A	645	Communicate sample evaluation

C-4 A0 Node Tree Outline CE Process

Top Level Drawing
Create Integrated Apparel Product Development A0

Design for Quality 1		
A	11	Design products for consumer requirements
A	111	Conceptualize line for target market
A	1111	Develop design & business goals: problem recognition
A	1112	Conceptualize line for target market
A	1113	Observe consumers
A	1114	Conduct & evaluate wear tests & garment tests
A	1115	Evaluate customer returns & consumer phone calls
A	112	Set design objectives
A	1121	Define & set theme direction
A	1122	Sketch reference items (e.g., Garments, art objects)
A	113	Design products with an attractive look & feel
A	1131	Design attractive products
A	11311	Create theme concepts
A	11312	Review print package
A	11313	Review prototype
A	11314	Decide optimum solution
A	11315	Generate & evaluate change orders
A	12	Select high quality components
A	121	Establish quality standards for garments
A	122	Evaluate color quality
A	1221	Write color formulation
A	1222	Evaluate & narrow colors
A	1223	Select colors
A	1224	Evaluate fabric quality
A	123	Review style request
A	124	Merchandise the line
A	125	Evaluate & specify fabrics
A	13	Benchmarking
A	131	Shop foreign markets
A	132	Shop domestic markets
A	133	Evaluate previous season's best-sellers
A	134	Implement specification change
A	14	Design product to minimize manufacture variation
A	141	Create prints
A	1411	Create painting (manual or CAD)
A	1412	Determine order to pitch by & color position
A	1413	Editing & modifying art for printing
A	1414	Clean up color trash
A	1415	Fill colors
A	1416	Approve strikeoff

(table continues)

A	142	Create & assess color
A	1421	Send color standard to textile vendor
A	1422	Match lab dip to color standard
A	1423	Write color formulation
A	1424	Create color tabs
A	1425	Perfect manual or CAD coloration
A	1426	Implement piece dye for garments
A	1431	Develop full fashion knitting specifications
A	1432	Communicate knitting requirements
A	1433	Give essentials to prototype sewing
A	144	Make decisions
A	1441	Conduct concepts meeting
A	1442	Evaluate sample appearance
A	1443	Engineering evaluates sample construction
A	1444	Communicate sample evaluation
A	1445	Evaluate cutting & sewing problems
A	15	Use specific values for design parameters
A	151	Specify color parameters
A	1511	Develop color for piece dye (yard goods)
A	1512	Approve dyed color samples
A	1513	Compare color submit to color standard
A	152	Create patterns & prototypes
A	1521	Prototyping
A	15211	Check prototype
A	15212	Assess prototype for fit
A	15213	Revise patterns & prototype
A	15214	Perform outside special operation: laundering
A	15215	Approve prototype
A	1522	Verify specification correctness
A	1524	Determine quality features
A	153	Grading patterns
A	1531	Develop grade rules & specifications
A	1532	Grade patterns
A	1533	Review nested plots
A	16	Maximize average part level
A	1611	Create basic pattern block
A	1612	Check marker & evaluate fabric utilization

Design for Enabling Technology 2

A	21	Optimize design information, use digital product model
A	211	Make decisions
A	2111	Determine minimum plan
A	2112	Determine category plan
A	2113	Conduct line review/sales forecast
A	2114	Develop sales sheets
A	212	Communicate piece good information
A	2121	Identify piece goods
A	2122	Track samples until plant receipt
A	2123	Track samples & special operations

(table continues)

A	2124	Review sample fabric report
A	213	Evaluate garment for automation adaptability
A	22	Store information in consistent, non redundant manner
A	221	Catalog color specifications
A	2211	Compile color library
A	2212	Finalize color palette
A	2213	Assign style/lot number
A	2214	Assign fabric codes
A	2215	Write color formulation
A	222	Create cataloging for patterns & markers
A	2221	Create specifications & sample package
A	2222	Write knitting manufacturing specifications
A	2223	Check marker & evaluate fabric utilization
A	223	Disseminate & digital transfer of information
A	2231	Review line sheets
A	2232	Enter line sheets into database
A	2233	Disseminate line sheets (manual or electronic)
A	2234	Send package to engraver
A	2235	Transfer marker
A	2236	Send sample marker to plants
A	23	Use accumulated design information
A	231	Use 2-d or 3-D CAD system
A	2311	Scan reference item
A	2312	Sketch designs
A	2313	Determine pattern step & repeat
A	2314	Send package to engraver
A	232	Determine market trends
A	2321	Search environment for information
A	2322	Understand marketing concept
A	2323	Observe consumers
A	233	Create designs
A	2331	Use reference library for fabric & silhouette
A	2332	Buy reference items
A	2333	Sketch reference items
A	2334	Design carryover garments (bodies)
A	2335	Create basic pattern block
A	2336	Create carryover garments
A	234	Make decisions
A	2341	Determine category plan
A	2342	Project fabric & trim
A	2343	Conduct classification analysis

Design for Manufacturability 3

A	31	Design producability into product at start
A	311	Plan equipment needs
A	3111	Evaluate garments for machine efficiency
A	3112	Evaluate garments for automation adaptability
A	3113	Evaluate garment tooling equipment

(table continues)

A	3114	Review garment for nonstandard operations
A	3115	Evaluate garments for equipment limitations
A	312	Produce prototypes
A	3121	Give essentials to prototype sewing
A	3122	Create engineered fabrics & garment
A	3123	Assemble prototype sample garment
A	3124	Create first pattern
A	313	Planning resource needs
A	3131	Submit pattern & marking instructions
A	3132	Request new fabric, trim or sewing application
A	3133	Determine product affordability
A	3134	Determine & purchase sample yardage quantity
A	314	Managing samples
A	3141	Assign sample production
A	3142	Generate samples
A	3143	Determine specifications
A	3144	Write knitting manufacturing specifications
A	3145	Write knit specifications for machine (FFK)
A	315	Produce samples
A	3151	Submit pattern & marking instructions
A	3152	Produce sewn samples
A	3153	Evaluate sample appearance
A	3154	Engineering evaluates sample construction
A	3155	Pattern/marker change request from manufacturing
A	32	Inspect or measuring at the source
A	321	Generate sample purchase order
A	322	Relay fabric reports
A	323	Assess for quality
A	3231	Train quality supervisors on manufacturing process
A	3232	Create specifications & sample package
A	3233	Track samples (plant level)
A	3234	Evaluate cutting/sewing problems
A	324	Observe manufacturing process
A	33	Design for ease of assembly
A	331	Evaluate garment sewability
A	332	Evaluate sewability of fabric/trim
A	333	Improve manufacturing quality
A	334	Determine & write routing
A	335	Manage delay in production process
A	34	Design for ease of fabrication
A	341	Developing raw material for ease of fabrication
A	3411	Identify piece goods
A	3412	Identify trims & findings
A	3413	Prepare fabric for finish
A	3414	Slit fabric
A	342	Perform in-house special operation
A	343	Monitor outside special operations process
A	344	Lay multiple fabric sample costing marker
A	345	Create markers (multiple fabrics)

(table continues)

Design for Life Cycle Inspectability 4		
A	41	Specify product parameters
A	411	Establish & assess color parameters
A	4111	Send color standard to textile vendor
A	4112	Log standard, send to colorist
A	4113	Evaluate piece good quality
A	4114	Compare color submit to color standard
A	412	Establish & assess fabric quality parameters
A	4121	Evaluate fabric quality
A	4122	Control, inspect griege goods
A	4123	Tenter fabric
A	4124	Evaluate fabric problem
A	413	Run garment quality test
A	414	Determine category plan
A	42	Involve quality assurance early
A	421	Set procedure for substandard fabric acceptance
A	422	Test textile piece goods
A	423	Submit piece good test
A	424	Sew trim, piece goods or test cut
A	425	Test yarn weight (FFK)
A	43	Use of geometric dimensioning & tolerancing
A	431	Conduct in-process & final sample inspection
A	432	Inspect griege garment
A	44	Consider automated equipment compatibility
A	441	Evaluate garment sewability

Design for Reliability A5		
A	51	Design, build prototypes & test iterations
A	511	Design prototypes
A	5111	Develop design & business goals
A	5112	Use company mission statement
A	5113	Evaluate garment bodies
A	5114	Complete line sheet
A	512	Coordinate raw materials for garment
A	5121	Identify piece goods
A	5122	Identify trims & findings
A	513	Grade patterns
A	5131	Grade patterns & submit instructions
A	5132	Develop grade rules & specifications
A	514	Manufacture prototypes
A	5141	Create first pattern
A	5142	Proof pattern measure & check specifications
A	5143	Evaluate prototype: design assessment
A	5144	Review prototype manufacturability
A	52	Involve reliability engineers in design
A	521	Evaluate & specify fabrics
A	522	Edit & modify art designs for printing
A	523	Perfect coloration (manual or CAD)

(table continues)

A	53	Build functionality into products
A	531	Assess prototype for fit
A	532	Create basic pattern block
A	533	Give essentials for prototype sewing
A	54	Participate in vendor/partner relationships
A	541	Collaborating design with industry partners
A	5411	Search environment for information
A	5412	Participate in textile concept meetings with vendors
A	5413	Knit textures circular knitting
A	5414	Adapt & maintain vendor performance certification
A	542	Generate color
A	5421	Finalize color palette
A	5422	Implement color process
A	5423	Write color formulation
A	5424	Create color tabs
A	543	Approve solid & print fabric colors
A	5431	Approve color tabs
A	5432	Approve color
A	5433	Match lab dip to color standard
A	5434	Edit & modify art for printing
A	544	Create painting & engraving
A	5441	Create painting (CAD or manual
A	5442	Determine order to pitch by & color position
A	5443	Create technique effects
A	5444	Create technical set up
A	5445	Separate colors
A	55	Use proven standard parts
A	551	Engrave screens automatic process
A	552	Engrave screens manual process
A	56	Improve product reliability to exceed customer expectations
A	561	Determine strategy for reorderable core items
A	562	Finalize fabric prints & textures
A	563	Draw colors through strainer
A	564	Print leader cloth

Design for Life Cycle Maintainability 6

A	61	Design products for easy maintenance, repair & replacement
A	611	Specifying fabric characteristics
A	6111	Identify piece goods
A	6112	Test textile piece goods
A	6113	Develop full fashion knitting specifications (FFK)
A	6114	Develop flat knitting specifications (FFK)
A	612	Proof pattern: measure & check specifications
A	613	Prototype finishing
A	614	Send prototype to special operations
A	62	Use of tradeoff considerations
A	621	Create carryover garments
A	63	Use available, inexpensive parts
A	631	Determine strategy for reorderable core items

(table continues)

Design for Cost 7		
A	71	Use target costs for products
A	711	Calculate profit margins
A	712	Conduct retail pricing analysis
A	713	Price the line
A	72	Use a tracking system that monitors cost targets
A	721	Generate sample purchase order
A	722	Calculate first cost components
A	7221	Lay sample costing marker
A	7222	Check marker & evaluate fabric utilization
A	7223	Calculate first cost
A	7224	Approve marker
A	723	Conduct costing
A	7231	Calculate regular cost
A	7232	Calculate sample direct & indirect costs
A	7233	Review cost sheets
A	731	Finalize fabric ideas
A	732	Style art design to meet customer price structure
A	733	Negotiate sample fabric prices & cost assignment
A	734	Review style request

Appendix D

Data Collection Instruments

D-1 Company Interview Sample Letter

Cynthia L. Regan
Ph.D. Candidate and Dept. of Energy Fellow
Virginia Tech

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103 Wallace Hall
Blacksburg, VA 24061
FAX (540)231-4516
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March xx, 1995

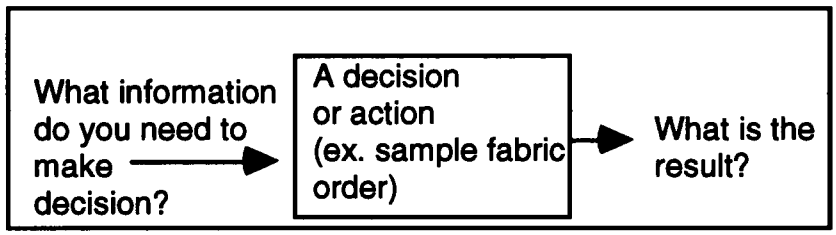
Ms. Xxx
xxx
xxx
xxx

Dear xxx

I am looking forward to our meeting on March x from 11:00 AM - 12:00 PM. I anticipate that much of information I will be asking for is "in a person's head", rather than on paper; so, you can approach the meeting as a brainstorming session. You are welcome to bring documents that may help with discussion.

Merchandising Work Flow
At our meeting, we will create a merchandising work flow process that has:

- the steps in the merchandising process
- the information that you need to make certain decisions (see diagram)
- importance of decisions made during merchandising
- the timing of decisions during merchandising
- dependence of one decision on others for merchandising



Merchandising Process Performance

I would like to discuss the current merchandising process. The questions I will ask are:

- How much variation have you experienced in the time required in processing merchandise line requirements (i.e., placing sample fabric orders)?
- How many times do you usually revise a merchandising plan?
- How do you know if the merchandising process is correct?
- How would you describe the quality of processing merchandising paperwork?
- How do you find out whether the merchandising process is correct (who tells you)?
- How do you measure the quality of what you receive as inputs (information/instructions) to create a merchandise line?
- How much variation have you experienced in the scheduling line development requirements?

Our discussion should provide some interesting insights.

Cordially,

Cynthia Regan

D-2 Questionnaire – Evaluation of the *To Be* Environment

Please look at the charts posted on the wall.

The design and product development activities have been rearranged into the concurrent engineering framework. Notice that some activities (e.g., reviewing designs for automation capability) have been moved up in the process and some activities (e.g., identifying piece goods) have been moved down in the process. How do you think the rearranging of activities could potentially affect time, cost, and quality of the design and product development process?

It was indicated that in the current process, the ability to stay on calendar was very difficult. In the new process, do you think that time, or the flow of activities has potential for:

good improvement			moderate improvement		little improvement		no improvement		don't know	
10	9	8	7	6	5	4	3	2	1	0

Please Explain

Some activities, (e.g., rework, overtime) increase the cost of the current product development process. In the new process, do you think that avoiding excess cost has potential for:

good improvement			moderate improvement		little improvement		no improvement		don't know	
10	9	8	7	6	5	4	3	2	1	0

Please Explain

It was indicated, in the current process, that quality was decreased due to rush work, and peaks and valleys of demand (e.g., producing samples). Do you think the rearranging of activities could create a better flow and has potential for:

good improvement			moderate improvement		little improvement		no improvement		don't know	
10	9	8	7	6	5	4	3	2	1	0

Please Explain

Based on your experience, how do you feel that the inclusion of the virtual team could potentially improve activities in Design for Quality?

	good improvement		moderate improvement		little improvement		no improvement		don't know
	10	9	8	7	6	5	4	3	2	1	0
time											
cost											
quality											

Please Explain

Based on your experience, how do you feel that the inclusion of the virtual team could potentially improve activities in Design for Enabling Technology?

	good improvement		moderate improvement		little improvement		no improvement		don't know
	10	9	8	7	6	5	4	3	2	1	0
time											
cost											
quality											

Please Explain

Based on your experience, how do you feel that the inclusion of the virtual team could potentially improve activities in Design for Manufacturability?

	good improvement		moderate improvement		little improvement		no improvement		don't know
	10	9	8	7	6	5	4	3	2	1	0
time											
cost											
quality											

Please Explain

Based on your experience, how do you feel that the inclusion of the virtual team could potentially improve activities in Design for Life Cycle Reliability?

	good improvement		moderate improvement		little improvement		no improvement		don't know
	10	9	8	7	6	5	4	3	2	1	0
time											
cost											
quality											

Please Explain

Based on your experience, how do you feel that the inclusion of the virtual team could potentially improve activities in Design for Life Cycle Inspectability?

	good improvement		moderate improvement		little improvement		no improvement		don't know	
	10	9	8	7	6	5	4	3	2	1	0
time											
cost											
quality											

Please Explain

Based on your experience, how do you feel that the inclusion of the virtual team could potentially improve activities in Design for Life Cycle Maintainability?

	good improvement		moderate improvement		little improvement		no improvement		don't know	
	10	9	8	7	6	5	4	3	2	1	0
time											
cost											
quality											

Please Explain

Based on your experience, how do you feel that the inclusion of the virtual team could potentially improve activities in Design for Cost?

	good improvement		moderate improvement		little improvement		no improvement		don't know	
	10	9	8	7	6	5	4	3	2	1	0
time											
cost											
quality											

Please Explain

Figure D-1 Survey Instrument

CE Constructs Applicable to Apparel

Design For Manufacturability, Quality, Cost, Enabling Technology and Life Cycle

CE Design For Manufacturability, Quality, Cost, Enabling Technology and Life cycle

COMPONENTS OF CONCURRENT ENGINEERING (CE)	Yes, we use all the time	Yes, we use sometimes	No, wish we used	No, not applicable for apparel	Don't know
DESIGN FOR MANUFACTURABILITY The use of:					
Manufacturability considered at start					
Producability designed into product					
Simplifying and reducing the number of parts					
Standardizing and using common parts and materials					
Design for ease of fabrication					
Mistake-proof product design & assembly					
Parts orientation to minimize non-value added activities					
Minimizing flexible parts and interconnections					
Design for ease of assembly					
Design for efficient joining and fastening					
Design modular products to facilitate assembly					
Ergonomics and human factors requirements					
Group technology (cellular or dedicated machines)					
Minimal handling (standardized carriers, adaptable carriers)					
Inspection or measurement at the source					
Reducing machine or job set-up time					
Management systems and team organization					
Minimizing design variation					
DESIGN FOR QUALITY The use of:					
Designing products to meet customer requirements					
Quality Function Deployment/House of Quality					
Selecting high quality components					
Designing products with an attractive look and feel					

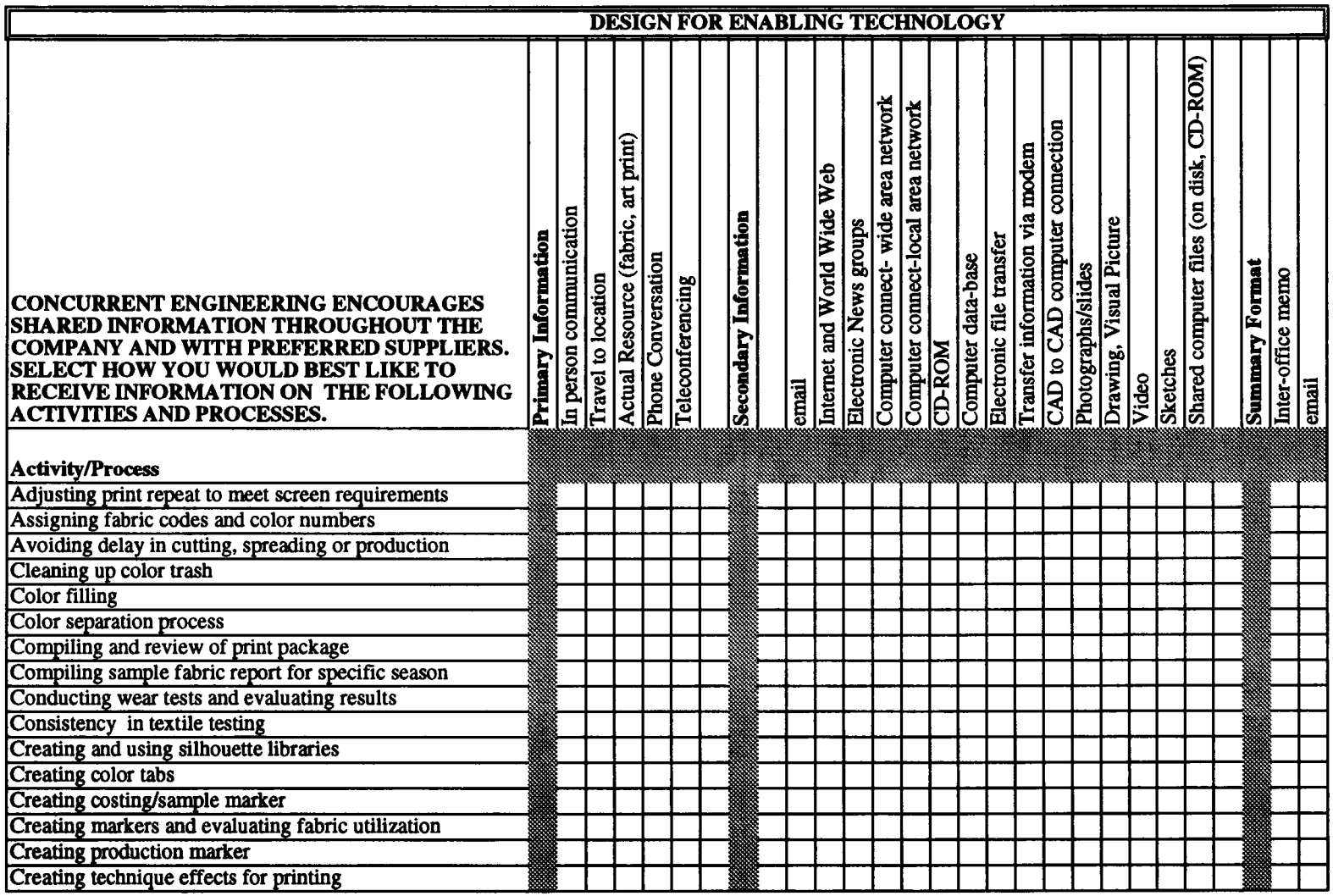
COMPONENTS OF CONCURRENT ENGINEERING (CE)	Yes, we use all the time	Yes, we use sometimes	Wish we used	No, not applicable for apparel	Don't know
DESIGN FOR QUALITY (continued) **The use of:**					
Designing a robust product to counter or minimize potential variation in product manufacture					
Taguchi quality engineering					
Building in functionality of the product					
Specific values for design parameters					
Acceptable tolerances					
Maximizing average part quality level					
Minimizing the number of parts					
Continuously improving product reliability performance to exceed customer expectations					
Benchmarking					
DESIGN FOR THE LIFE CYCLE **The use of:**					
Life cycle Inspectability					
Early involvement of quality assurance (QA)					
Geometric dimensioning & tolerancing					
Specification of product parameters					
Automated equipment compatibility					
Built-in test diagnostic capability					
Standard connections					
Having the ability to test and diagnose problems with standard test instruments					

COMPONENTS OF CONCURRENT ENGINEERING (CE)	Yes, we use all the time	Yes, we use sometimes	Wish we used	No, not applicable for apparel	Don't know
DESIGN FOR THE LIFE CYCLE (continued) **The use of:**					
Life cycle Reliability					
Designing building prototypes and testing iterations					
Reliability engineers involved in design					
Computer-Aided Engineering tools to test					
Taguchi quality engineering					
Vendor/partner relationships					
Proven standard parts					
Life cycle Maintainability					
Designing products for easy maintenance, repair, and replacement					
Trade-off considerations					
Modular design replacement					
Available, inexpensive parts					
Analyzing mean time to replace (MTTR)					
DESIGN FOR COST **The use of:**					
Target costs for products					
A tracking system that monitors cost targets during product development					
Life-cycle costing					
DESIGN FOR ENABLING TECHNOLOGY **The use of:**					
Digital product models (e.g., computer data base)					
A digital product model to maintain and optimize product/process design information					
storing information in logical, consistent, non redundant and reusable manner					
Accumulated design knowledge to be repeatedly used					

COMPONENTS OF CONCURRENT ENGINEERING (CE)	Yes, we use all the time	Yes, we use sometimes	Wish we used	No, not applicable for apparel	Don't know
DESIGN FOR ENABLING TECHNOLOGY **The use of:**					
Digital product model data available throughout company					
Avoid paper drawings					
2D CAD or 3D CAD systems					
CAD solid modeling					
CAD feature based representation					
Process Design					
Specifying design and layout of production equipment					
Process plans that define how product will be manufactured					
Parts and assembly programming					
Tool and fixture design					
Data Interchange					
Digital product data extending beyond company					
Electronic data interchange					
Product Data Exchange using STEP					

Figure D-2 Survey Instrument

Design for Enabling Technology


DESIGN FOR ENABLING TECHNOLOGY
CONCURRENT ENGINEERING ENCOURAGES SHARED INFORMATION THROUGHOUT THE COMPANY AND WITH PREFERRED SUPPLIERS. SELECT HOW YOU WOULD BEST LIKE TO RECEIVE INFORMATION ON THE FOLLOWING ACTIVITIES AND PROCESSES.
Primary Information
In person communication
Travel to location
Actual Resource (fabric, art print)
Phone Conversation
Teleconferencing
Secondary Information
email
Internet and World Wide Web
Electronic News groups
Computer connect- wide area network
Computer connect-local area network
CD-ROM
Computer data-base
Electronic file transfer
Transfer information via modem
CAD to CAD computer connection
Photographs/slides
Drawing, Visual Picture
Video
Sketches
Shared computer files (on disk, CD-ROM)
Summary Format
Inter-office memo
email
Activity/Process
Adjusting print repeat to meet screen requirements
Assigning fabric codes and color numbers
Avoiding delay in cutting, spreading or production
Cleaning up color trash
Color filling
Color separation process
Compiling and review of print package
Compiling sample fabric report for specific season
Conducting wear tests and evaluating results
Consistency in textile testing
Creating and using silhouette libraries
Creating color tabs
Creating costing/sample marker
Creating markers and evaluating fabric utilization
Creating production marker
Creating technique effects for printing

| CONCURRENT ENGINEERING ENCOURAGES SHARED INFORMATION THROUGHOUT EVERYONE IN THE COMPANY AND PREFERRED SUPPLIERS. SELECT HOW YOU WOULD BEST LIKE TO RECEIVE INFORMATION ON THE FOLLOWING ACTIVITIES AND PROCESSES. | | |

CONCURRENT ENGINEERING ENCOURAGES SHARED INFORMATION THROUGHOUT EVERYONE IN THE COMPANY AND PREFERRED SUPPLIERS. SELECT HOW YOU WOULD BEST LIKE TO RECEIVE INFORMATION ON THE FOLLOWING ACTIVITIES AND PROCESSES.	Evaluating garments for meeting quality specifications	Evaluating print problems (e.g., color does not transfer)	Evaluating sewability of new fabrics	Experimental piece goods testing process	Fabric quality control process	Fabric tentering process	Generating color formulations	Getting prints in correct coloration	Identifying piece goods	Identifying trims and findings	Lab dip approval process	Lab dip process	Laser engraving process	Manufacturing having difficulty meeting quality standards	Matching lab dip to color standard	Observation of manufacturing process	Photo engraving process
Primary Information																	
In person communication																	
Travel to location																	
Actual Resource (fabric, art print)																	
Phone Conversation																	
Teleconferencing																	
Secondary Information																	
email																	
Internet and World Wide Web																	
Electronic News groups																	
Computer connect- wide area network																	
Computer connect-local area network																	
CD-ROM																	
Computer data-base																	
Electronic file transfer																	
Transfer information via modem																	
CAD to CAD computer connection																	
Photographs/slides																	
Drawing, Visual Picture																	
Video																	
Sketches																	
Shared computer files (on disk, CD-ROM)																	
Summary Format																	
Inter-office memo																	
email																	

CONCURRENT ENGINEERING ENCOURAGES SHARED INFORMATION THROUGHOUT EVERYONE IN THE COMPANY AND PREFERRED SUPPLIERS. SELECT HOW YOU WOULD BEST LIKE TO RECEIVE INFORMATION ON THE FOLLOWING ACTIVITIES AND PROCESSES.	Manufacturing process performance training	Piece goods not meeting quality standards	Preparing fabric for finish process (e.g., scouring)	Print themes: evaluating and creating print designs	Printing leader cloth	Printing on paper--transferring color to paper	Printing the strike-off	Proofing the pattern for approval	Scanning the original design	Scheduling strike-offs	Scribing the design	Strike-off approval process	Style development process	Textile testing process	Trapping the color	Using reference fabrics, garments and trims	Vendor performance standard process
Primary Information																	
In person communication																	
Travel to location																	
Actual Resource (fabric, art print)																	
Phone Conversation																	
Teleconferencing																	
Secondary Information																	
email																	
Internet and World Wide Web																	
Electronic News groups																	
Computer connect- wide area network																	
Computer connect-local area network																	
CD-ROM																	
Computer data-base																	
Electronic file transfer																	
Transfer information via modem																	
CAD to CAD computer connection																	
Photographs/slides																	
Drawing, Visual Picture																	
Video																	
Sketches																	
Shared computer files (on disk, CD-ROM)																	
Summary Format																	
Inter-office memo																	
email																	

Table D-1 Collapsed Enabling Technology Categories

Enabling Technology Mechanisms

General Categories and Specific Enabling Technologies within Categories

---

Communication in-person

Communication-other
- Phone conversation
- Teleconferencing
- Interoffice memo
- Overnight mail
- Travel to location

Communication Via Computer
- Computer wide area network
- Computer local area network
- Electronic new groups
- Electronic mail
- Internet
- World Wide Web

Actual Resources
- Drawing, visual, picture
- Photographs, slides
- Sketches
- Video

Computer-Aided Design Data (CAD/data)
- CAD to CAD computer connection
- CD-ROM (read only)
- Computer data base
- Electronic file transfer
- Optical disk (read and write)
- Shared computer files (on disk, CD ROM)
- On-line computer system/mainframe

Figure D-3 Survey Instrument

Creation of a Multi-Disciplinary Team

For your multi-disciplinary team, indicate who should be Responsible (R) for providing information, should Provide Input (I), or should be Notified (N) for the following activities and processes.	Department/Individual
Designer	Design
Design Associate	
Product Engineer	Engineering
Cost Engineer	
Plant Manager	Manufacturing
Product Scheduler	
Knitting Operator	
Assembly Operator	
Knitting Supervisor	
Assembly Supervisor	
Merchandiser	Merchandising
Merchandise Associate	
CAD Artist	Merchandise Services
Forecast Associate	
R & D Manager	Research & Development
R & D Assistant	
QA- Manager	Service Support
QA- Supervisor	
Pattern Maker	
Pattern Supervisor	
Marker Maker	
Protoype Supervisor	
Fabric Buyer	Operations
Machinist	Knit Pattern Making
Textile Manufacturer	
Textile Colorist	Dye House
Textile Account Rep.	Supplier
Textile Engraver	Corporate Office

Adjusting garment fit	Assigning garment style codes and color numbers	Assigning sample production to plant(s)	Avoiding delays in dyeing, knitting or assembly	Building quality features into garment	Calculating direct and indirect costs	Calculating first cost	Calculating margins	Checking chain program for consistent manufacturing quality	Classification style analysis	Communication/meeting regarding prototype development

For your multi-disciplinary team, indicate who should be Responsible (R) for providing information, should Provide Input (I), or should be Notified (N) for the following activities and processes.																	
Competitor garment and size analysis																	
Compiling sample history report for specific season																	
Concept Meeting 3-Line slush meeting																	
Concept Meeting 2-Merchandise committee meeting																	
Concept Meeting 1 -Strategic Business Unit Meeting																	
Conducting wear tests and evaluating results																	
Consistency in textile testing																	
Creating & evaluating yarn yield report																	
Creating and using silhouette libraries																	
Creating color tabs/cards																	
Creating first prototype																	
Creating new styles (bodies)																	
Creating the knit pattern guide (courses & wales)																	
Creating/revising CAD sales sheets																	
Decision making: selecting and determining colors																	
Design objectives: setting the theme direction																	
Determining and conveying yarn & knitted fabric projection																	
Determining routing																	
																	Designer
																	Design Associate
																	Product Engineer
																	Cost Engineer
																	Plant Manager
																	Product Scheduler
																	Knitting Operator
																	Assembly Operator
																	Knitting Supervisor
																	Assembly Supervisor
																	Merchandiser
																	Merchandise Associate
																	CAD Artist
																	Forecast Associate
																	R & D Manager
																	R & D Assistant
																	QA- Manager
																	QA- Supervisor
																	Pattern Maker
																	Pattern Supervisor
																	Marker Maker
																	Protoype Supervisor
																	Fabric Buyer
																	Machinist
																	Textile Manufacturer
																	Textile Colorist
																	Textile Account Rep.
																	Textile Engraver

For your multi-disciplinary team, indicate who should be Responsible (R) for providing information, should Provide Input (I), or should be Notified (N) for the following activities and processes.	Designer	Design Associate		Product Engineer	Cost Engineer		Plant Manager	Product Scheduler	Knitting Operator	Assembly Operator	Knitting Supervisor	Assembly Supervisor		Merchandiser	Merchandise Associate	CAD Artist	Forecast Associate		R & D Manager	R & D Assistant		QA- Manager	QA- Supervisor	Pattern Maker	Pattern Supervisor	Marker Maker	Protoype Supervisor		Fabric Buyer	Machinist	Textile Manufacturer	Textile Colorist	Textile Account Rep.	Textile Engraver
Determining set styles, single styles, and coordinates																																		
Determining strategy for reorderable core																																		
Determining the desired garment design wanted																																		
Developing and using color standards																																		
Developing grade rules																																		
Evaluating new knitting designs																																		
Developmental knit pattern process (e.g., new cable design)																																		
Drawing sketches to reflect design revision																																		
Electronic transfer of CAD file																																		
Engineering tracking process																																		
Evaluating and specifying new yarns																																		
Evaluating customer returns and consumer phone calls																																		
Evaluating designs for "oddball" operations																																		
Evaluating designs for machine efficiency																																		
Evaluating designs for need or purchase of tooling/machines																																		
Evaluating designs for resources needed																																		
Evaluating designs requested for automation adaptability																																		

For your multi-disciplinary team, indicate who should be Responsible (R) for providing information, should Provide Input (I), or should be Notified (N) for the following activities and processes.																			
Evaluating designs requested for equipment limitations																			
Evaluating dye problems (e.g., color does not transfer)																			
Evaluating garments for meeting quality specifications																			
Evaluating knitability of new yarns																			
Evaluating optimal proposal: finalize merchandise line																			
Evaluating prototype for flat and full fashion knitting requirements																			
Evaluating yarns: content and finish characteristics																			
Evaluation of sample assessment																			
Experimental testing process (e.g., checking course/wale measurement)																			
Filling out style description sheet (proto/sample request)																			
Focus group observation and using the information																			
Generating and evaluating change orders																			
Generating bill of materials																			
Generating color formulations																			
Getting dye color in correct and consistent coloration																			
Grading garment sizes																			
Identifying needs: yarn gauge, ends, appearance																			
Identifying trims and findings																			
																			Designer
																			Design Associate
																			Product Engineer
																			Cost Engineer
																			Plant Manager
																			Product Scheduler
																			Knitting Operator
																			Assembly Operator
																			Knitting Supervisor
																			Assembly Supervisor
																			Merchandiser
																			Merchandise Associate
																			CAD Artist
																			Forecast Associate
																			R & D Manager
																			R & D Assistant
																			QA- Manager
																			QA- Supervisor
																			Pattern Maker
																			Pattern Supervisor
																			Marker Maker
																			Protoype Supervisor
																			Fabric Buyer
																			Machinist
																			Textile Manufacturer
																			Textile Colorist
																			Textile Account Rep.
																			Textile Engraver

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For your multi-disciplinary team, indicate who should be Responsible (R) for providing information, should Provide Input (I), or should be Notified (N) for the following activities and processes.	Designer	Design Associate		Product Engineer	Cost Engineer		Plant Manager	Product Scheduler	Knitting Operator	Assembly Operator	Knitting Supervisor	Assembly Supervisor		Merchandiser	Merchandise Associate	CAD Artist	Forecast Associate		R & D Manager	R & D Assistant		QA- Manager	QA- Supervisor	Pattern Maker	Pattern Supervisor	Marker Maker	Protoype Supervisor		Fabric Buyer	Machinist	Textile Manufacturer	Textile Colorist	Textile Account Rep.	Textile Engraver
Purchase and determine quantity of sample yarns																																		
Putting the color story together																																		
Recalculating prototype measurements to meet specifications																																		
Relaying style - yarn yield report to plant																																		
Request for new knitting or assembly manufacture application																																		
Requests for prototype change from manufacturing																																		
Retail pricing analysis																																		
Reusing knit patterns and using carry-over garments																																		
Review sample production: handling, quality, rates																																		
Reviewing cost sheets																																		
Reviewing grading results																																		
Reviewing margins																																		
Reviewing prototype for size consistency- dimensional record																																		
Reviewing prototype line sheets																																		
Reviewing submitted sketches/reference garments																																		
Revising first prototype																																		
Sample/prototype laundering & finishing process																																		
Shipping prototypes and samples																																		
Textile testing process																																		

For your multi-disciplinary team, indicate who should be Responsible (R) for providing information, should Provide Input (I), or should be Notified (N) for the following activities and processes.											
Training quality supervisors on knitting/assembly process performance											
Using color shade libraries											
Using company mission guidelines in designs											
Using established knit pattern blocks											
Using reference yarns, garments and trims											
Vendor performance standard process											
Weight sheet development process											
Writing programs for knitting machines (chains)											
Yarn/raw material quality control process											
Yarns not meeting quality standards											
											Designer
											Design Associate
											Product Engineer
											Cost Engineer
											Plant Manager
											Product Scheduler
											Knitting Operator
											Assembly Operator
											Knitting Supervisor
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											Textile Colorist
											Textile Account Rep.
											Textile Engraver

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PUBLICATIONS

Regan, C., Kincade, D., & Sheldon, G. (in press). *Applicability of the engineering design process theory in the apparel design process.* Clothing and Textile Research Journal.

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Kincade, D. & Regan, C. (1994). *The use of technology by apparel manufacturers.* In M. M. Ahmad & W. G. Sullivan (Eds.), Flexible Automation and Integrated Manufacturing. New York: Begell House.

Regan, C. & Sheldon, G. (1989). *Teaching computer-aided apparel design.* Association of College Professors of Textiles and Clothing Conference Proceedings, 1988.