Demand **A**ctivated **M**anufacturing **A**rchitecture

Enterprise Simulation Analysis of the Nylon Jacket Pipeline

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This report was prepared by the DAMA Los Alamos Analysis Team. For Copies of this document, contact Jim Lovejoy, Textile/Clothing Technology Corporation [TC^2], (919)380-2184, or James Ostic, Los Alamos National Laboratory, (505)667-3941.

Preface

The purpose of this study was to identify ways in which time and cost might be removed from the production of L. L. Bean's® Warm-up Jacket through systems analysis and the application of supply chain management principles such as coordination and integration. The first three sections of this report provide an introduction, study objectives and a definition of generic supply chain problems as well as those specific to the Nylon Jacket Pipeline (NJP) respectively. Section four outlines the supply chain design components that should be included in any pipeline analysis including a generic architecture and methodology. In section five, results specific to the NJP analysis are documented. Finally, the last three sections include the project's activities, deliverables, recommendations and conclusions.

The proprietary information required to conduct this analysis has been documented and organized into a series of appendices so that any CRADA protected information may be selectively distributed only to those readers receiving the express consent of the NJP members. As such this report does not contain a complete set of these appendices.

Finally, the analysis team received much help and assistance from the following DAMA and industry personnel who supported this analysis: Leon Chapman (Sandia National Laboratory), Rol Fessenden and Bill Holden (L. L. Bean®), Tom Lang (Maldin Mills), Jim Lovejoy ([TC]^2), Jim Plouffe (E.I. DuPont de Nemours), Gail Travers (Cascade West Sportswear), and Doug Wilson (Glen Raven Mills). Special thanks to L. L. Bean® for its unwavering support and willingness to provide the sensitive information necessary to conduct a meaningful analysis.

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1. Introduction

The Demand Activated Manufacturing Architecture (DAMA) was initiated in 1993 to improve global competitiveness of the United States Integrated Textile Complex (ITC) (DAMA, 95). This American Textile Partnership (AMTEX) project is directed to provide those tools and technologies necessary to facilitate:

> *"A comprehensive business strategy to continually meet changing requirements of a competitive marketplace which promotes responsiveness to consumer demand, encourages business partnerships, makes effective use of resources and shortens the business cycle throughout the chain from raw materials to consumer. (AMTEX, 96)"*

In May of 1996, DAMA industry participants requested Los Alamos National Laboratory to provide a rapid response supply-chain analysis of the men's nylon Supplex® Warm-up Jacket, retailed by L.L. Bean® . The purpose of this study was to identify ways in which time and cost might be removed from the production of this garment through application of analytical tools. The Warm-up Jacket production is spread over five business segments specializing in the production of fiber and filament yarn, manufacture of textiles and apparels, and retail merchandising. The existing Nylon Jacket Pipeline (NJP) was benchmarked for performance and to provide insights into methods and standards which, if implemented, increase competitiveness and promote agility *within* and *between* supply-chain members. Besides L.L. Bean® , other supply-chain members included E. I. DuPont de Nemours, Glenn Raven Mills, Malden Mills, and Cascade West Sportswear.

The pipeline analysis was performed in a systematic fashion. Initially, study requirements were developed through interactions with supply-chain members. Once study objectives and problem definition tasks were completed, a generic supply-chain design architecture was developed. A methodology for supply-chain analysis lead to two analysis tasks: 1.) a static analysis of retail forcasting techniques; and 2.) a dynamic analysis of the integrated supply-chain using a simulation model. Recommendations on supply-chain improvements and areas of study research for future endeavors were also defined. This report includes documentation of the supply-chain design architecture, analysis methodology, and analysis results. In addition, study conclusions and recommendations are provided. Supporting information, including data and analysis which is considered to be company proprietary, has been consolidated into separate appendices.

2. Objectives

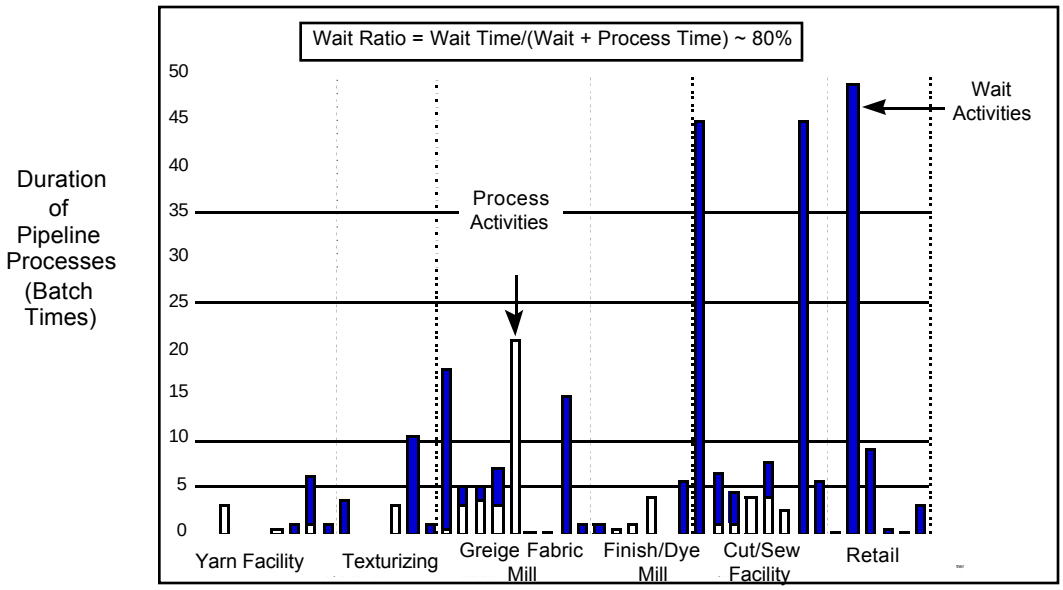
The focus of this study was to examine potential improvements in *interaction*s and *linkages* between supply-chain members, in contrast to re-engineering individual member's manufacturing processes. It was recognized that time was not available to attack supply-chain lead times, rather the focus required, a) the development of a generic methodology for supply-chain analysis, b) benchmarking the performance of the supply-chain, c) performing sensitivity analysis to identify potential improvements, and d) assessing responsiveness of the supply-chain to a product change. Quantitatively, this analysis characterized the value of reduced lead times and identified where costs might be removed from the existing supply-chain. Specifically, the following areas were targeted for improvement:

1. the impact of forecasting error on the performance of supply-chain member companies
2. benefits accrued to the supply-chain from implementing a produce-to-order versus a produce-to-stock inventory policy
3. different service levels and their impact on inventory levels and stockouts
4. value addition in the supply-chain, due to reduction in lead time from it's apparel manufacturing to retail sectors.

3. Problem Definition

The concept of supply-chain integration concerns managing coordinated information and material flows, plant operations, and logistics. An integrated supply-chain is flexible and agile in responding to consumer demand shifts without excessive cost overlays. The fundamental premise of this philosophy is; *synchronization* among multiple autonomous business entities represented within it. That is, improved coordination *within* and *between* various supply-chain members. The increased coordination can lead to reduction in lead times and costs, alignment of interdependent decision-making processes, and improvement in the overall performance of each member as well as the supply-chain.

In the case of the Nylon Jacket Pipeline (NJP) problem, Figure 1 demonstrates that a potential outcome of lack of coordination in the supply-chain is the *wait* between activities[1].



Mid-Range Process and Wait Times for Supplex and Parka Only -
Report on Site Visits and Meetings - Men's Nylon Supplex® Parka Product Team

Figure 1. Wait Characteristics of Nylon Supplex® Parka Pipeline

Further classification of these activities, depicted in Figure 2, suggests that major contributors to *wait* are the non-value added activities, namely, delay, setup, inspect, storage, and move/transport. (this figure sums the number of activities in each sector.) The prevalence of such activities points to structural weaknesses in the NJP system. Figure 3 provides a hierarchical breakdown of activities in the NJP system, and the opportunities for improvement offered by the problem.

[1] The focus of this study was redefined from the Ski Parka to the Warm-up Jacket midway through the analysis when it was determined that the current pipeline was no longer responsible for the production of Ski Parkas. Aside from styling differences, production of these two garments is virtually the same.

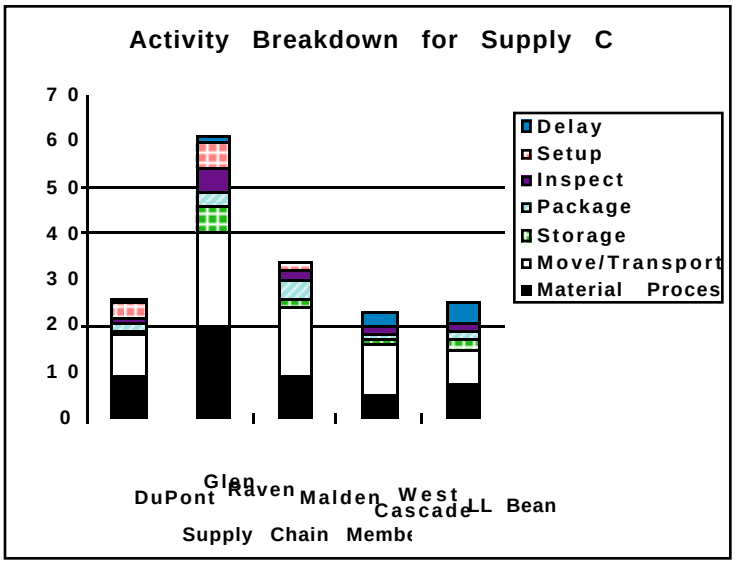


Figure 2. Activity Breakdown of Nylon Supplex® Parka Pipeline

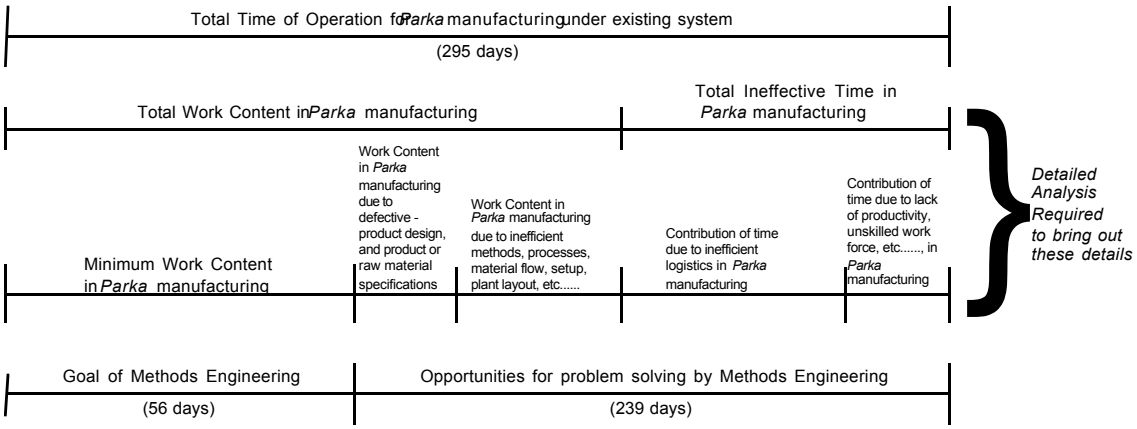


Figure 3. Manufacturing Time Line for the Nylon Supplex® Parka Pipeline

Coordination of such a diverse string of activities, however, requires addressing policy issues that have potential impact on the performance of the supply-chain enterprise. Some of these are:

1. inventory control and management of stock levels due to fluctuation in demand
2. cost variances due to production planning and scheduling
3. relationship of forecasting error to inventory cost
4. relationship of risks and inventory cost
5. marketing and promotion impact on demand.

In view of the highly seasonal demand for Nylon Jackets, coordination of production forecasts of members in the supply-chain is extremely important, in order to remain

competitive. Therefore, policy issues 1 and 3 mentioned above were analyzed in depth for the NJP problem.

4. Supply-Chain Design[2]

The analysis of interrelated issues in the NJP requires a framework for designing, modeling and implementing *inter* and *intra* member relationships in a specific problem area. Therefore, the problem solution strategy adapted in the NJP study has been to,

1. develop a generic architecture to create the appropriate structure, install proper controls, and implement principles of optimization to synchronize the supply-chain, and
2. implement a domain specific NJP forecasting model based on a cooperative system approach.

In this section, an integrated supply-chain framework is described. First, a generic architecture for a cooperative supply-chain system is discussed. Next, two specific representations of this architecture are modeled. Finally, a structured methodology to apply various tools and techniques is described. Enterprise decomposition, process modeling, work design and methods improvement, forecasting, and simulation are elements included within this methodology.

4.1 Supply-Chain Architecture

The supply-chain architecture proposed in this study is a prescriptive "method of design and construction" for a cooperative supply-chain system. It is based on the principles that a cooperative supply-chain system architecture should be generic to incorporate principles of coordination, negotiation, and compromise; yet specific to implement domain dependent supply-chain problem solving algorithms.

A supply-chain is a *society* (network of *Member*s, termed a *Group*) formed by autonomous business entities (and their systems) by bonding together to solve a common problem. With their collective and collaborative efforts, they sustain the progress of each Member as well as the Group. Collaboration between Members requires effective communication. In a collaborative environment, a Member may modify its norms of behavior to accommodate other Member's perspectives (Bond and Gasser, 1988; Gasser, 1991; Moulin and Chaib-Draa, 1996).

Following guiding principles are proposed for the supply-chain framework described in this report:

- supply-chain is a *Cooperative System*,
- supply-chain exists on *Group Dynamics* of its Members,
- *negotiation* and *compromise* are norms of operation in a supply-chain,
- supply-chain system solutions are *pareto-optimal* (*satisficing*), not optimizing, and
- *integration* in supply-chain is achieved through *synchronization*.

[2] A major portion of this section has been reproduced from the following article:
Chandra, C. (1996). Enterprise Architectural Framework for Supply-Chain Integration. Los Alamos National Laboratory, Los Alamos, N.M.

4.1.1 A Distributed Problem-Solving Hypothesis for a Cooperative Supply-Chain System

The system architecture of a cooperative supply-chain (CSC) is based on the distributed problem-solving approach, illustrated in Figure 4. The CSC is comprised of a Group and more than one Member. The network is arranged in the order -- flow of materials, processes, and information occurs between its Members. In the textile industry example depicted in Figure 4, consumer demand is relayed by retailer to -- apparel maker, textile manufacturer, fiber manufacturer, and ultimately to Cotton grower. Similarly, flow of material occurs in transforming -- cotton to yarn by fiber manufacturer, fiber to fabric by textile manufacturer, textile to apparel by apparel maker, and finally a name brand garment by retailer. The interaction between Members occurs as a *consumer* and a *provider*. Thus, an apparel maker assumes the role of a provider (of apparels) in its dealings with retailer (a consumer of apparels). However, the apparel maker acts as a consumer of fabric while dealing with a textile manufacturer (a provider of fabric). The CSC requires design and implementation of three primary components: structure, control, and optimization. We describe these below.

Structure. The CSC is a physically and logically distributed system of interacting components and elements of autonomous business entities. In the distributed problem-solving environment, the task of solving a problem is divided among a number of modules or nodes (autonomous business entities and their systems). The members cooperatively decompose and share knowledge on the problem and its evolving solutions. Interactions between Members in the form of cooperation and coordination are incorporated as problem-solving strategies for the system. Entity Group, is responsible for coordination throughout the supply-chain. Entity Member, brings specialized expert knowledge and manufacturing technology to the supply-chain. The decision-making process is centralized for the Group -- common goals and policies of the supply-chain are enforced by the Group on its Members. However, decision-making at Member is decentralized -- each Member pursues its own goals, objectives, and policies conceptually, independently of the Group, but pragmatically in congruence with Group goals. A common knowledge-base supports the CSC structure. Knowledge is assimilated for an *activity* (the lowest level of information) in a specific domain and aggregated for various decision-making levels in the enterprise.

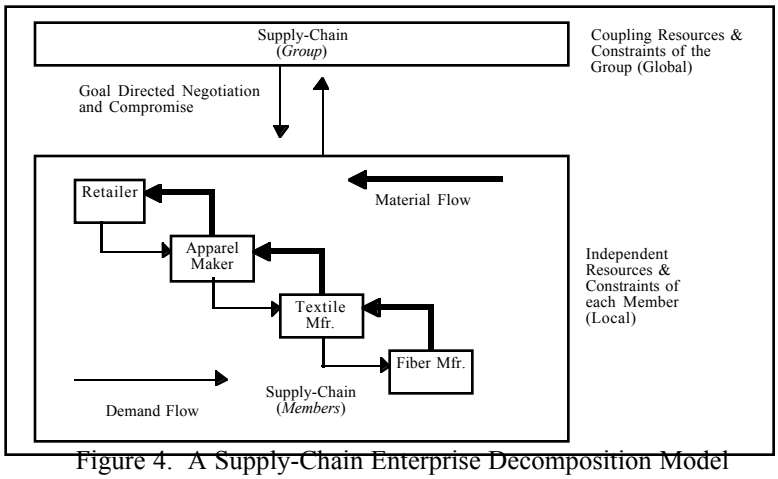


Figure 4. A Supply-Chain Enterprise Decomposition Model

Control in the CSC is maintained via goals, policies, and objectives that are logically aligned (*synchronized*) along the system's decision-making hierarchy. This is accomplished by applying principles of complementarity, consistency, and constriction to these control elements, as depicted in Figure 5. A vertical arrow between two decision-making levels signifies complementarity of controls at these levels. Thus, a primary goal at the strategic level must be complementary to a secondary goal at tactical and tertiary goal at the

operational levels. A horizontal arrow signifies consistency between control elements across a decision-making level. Thus, a strategic goal must be consistent with policies and objectives outlined for its implementation. A diagonal arrow denotes constriction between goals, policies and objectives between decision-making levels. Thus, a strategic *goal* will constrain *policies* to be implemented at the tactical level, which in turn will constrain *objectives* at the operational level.

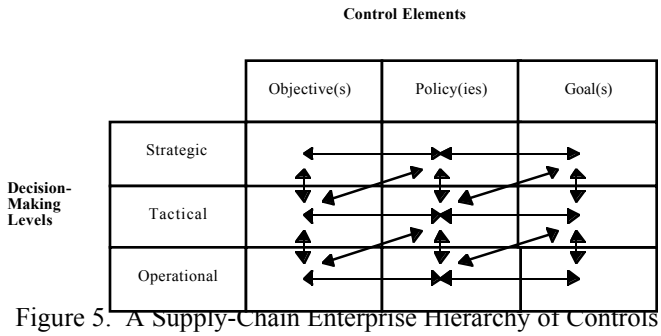
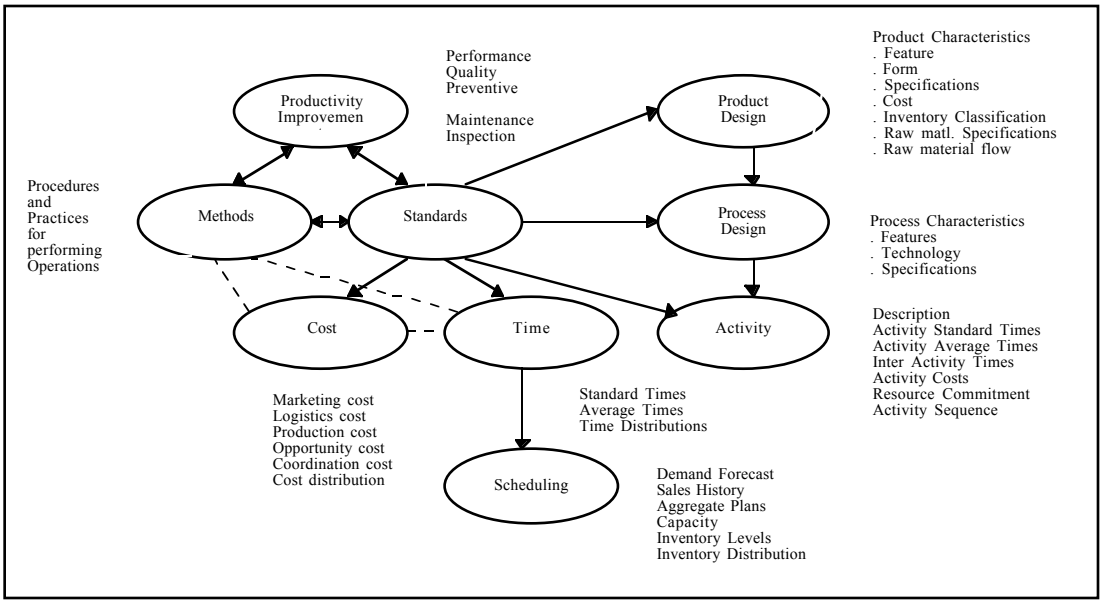


Figure 5. A Supply-Chain Enterprise Hierarchy of Controls

Optimization. The principle of optimization of the CSC system is enunciated by investigating relationships between *methods*, *standards*, and *costs* on the operation of the enterprise. Figure 6 depicts these relationships, summarized below:

- standards vs. costs,
- standards vs. productivity,
- standards vs. methods, and
- influence of methods and standards on product and process designs.



These relationships are first quantified through known *work design* and *methods improvement* techniques, and then represented as joint attributes of various *decision-making levels* and *control elements*, in the CSC system model (Nadler, 1970; Niebel, 1993).

The analysis of a CSC system focuses on interactions between its design components. That is, analyzing interactions between Members of the supply-chain for information sharing, defining controls and specifying roles and responsibilities, while adding value to the product. This requires identifying activities in the product-life-cycle, defining strategies for their implementation, and establishing performance criteria to measure their outcome. Figure 7 illustrates a structured approach to integrate CSC design components over the product and process life-cycles.

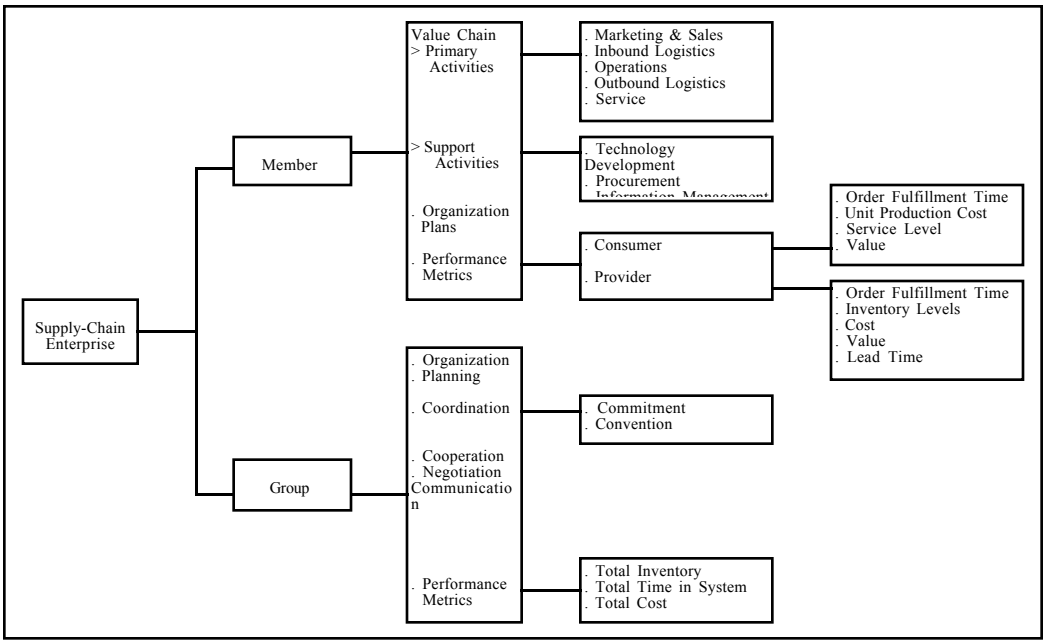


Figure 7. A Supply-Chain Enterprise Analysis Approach

4.1.1.1 Cooperative Supply-Chain System: A Member Perspective

Members of a CSC system in a distributed problem-solving architecture are *heterogeneous* (Durfee et al., 1989*)*. The degree of heterogeneity can be attributed to the implicit and explicit behaviors they portray within their internal organization, as well as in their dealings with other Members of the supply-chain. Some key factors that differentiate Members in terms of their heterogeneity are:

- rules for allocation and utilization of *resources*,
- methods and approaches utilized in *problem-solving*,
- degree of *adaptability* shown in negotiation and compromise, and
- extent of *inter* and *intra* activity interactions within the Member organization.

System analysis of a Member deals with evaluating the influence of these factors primarily on a Member's organization, and on their interactions with other Members of supply-chain. This is accomplished by (a) conducting a value analysis of primary activities as depicted in Table 1, and (b) identifying hierarchy of controls in the decision-making process of the Member enterprise as depicted in Table 2. The value analysis identifies what value is added to the product by various organizational functions. As mentioned earlier in Figure 5, control elements interact to respond to dynamic market conditions.

Figure 8 illustrates the architecture of a CSC Member enterprise. The integration of design components described in Section 4.1.1 is evident in this diagram. Decision-making models are aggregated from the lowest (activity) to the highest (Member) component of the enterprise. The transformation of material from one stage to the next, until final product is derived, occurs at the activity level. Transformation in the order-life-cycle occurs at the business level as the order is processed by marketing & sales, order entry, product design, production planning & scheduling, manufacturing, and shipping functions, respectively. Controls are passed at both inter (between operations along the model hierarchy) and intra (within operations belonging to the same function) levels to implement independent organizational goals, policies, and objectives.

Table 1. Member Enterprise Value Analysis

	Procurement	**Technology Development**	**Information Management**	**Others**
Marketing & Sales	. Buy advertising campaigns . Buy sales promotions	. Consumer market research . Incorporate market needs in the product	. Forecast demand and sales . Sales analysis . Track product performance	. Coordinate order processing
Inbound Logistics (*Receiving, Warehousing, Inventory Control, Production Planning*)	. Procure end-products . Procure raw-material for assembly and packaging		. Receive and track raw materials and end-products	. Manage storage of raw materials and end-products
Plant Operations (*Manufacturing, Inspection, Product Assembly, Product Packaging*)				. Quality inspection of finished product . Assemble end-product . Package end-product
Outbound Logistics (*Warehousing, Inventory Control, Shipping*)	. Procure shipment modes		. Inventory control of finished product . Track and report shipments	. Select shipment and routing modes . Consolidate order for a carrier
Service (*Organization and Management*)			. Manage inventory carrying, quality, backorder, and opportunity costs . Analyze cost variance	. Guarantee shipment schedules

Table 2. Member Enterprise Hierarchy of Controls

	Objective(s)	**Policy(ies)**	**Goal(s)**
Marketing	. Maximize customer service	. Implement a procure-to-stock policy	. Achieve a *x%* order-fill-rate of within *t* days order processing
Procurement Planning	. Maximize inventory turns	. Implement a JIT procurement policy	. Achieve *k* inventory turns
Warehouse Operations	. Minimize merchandising costs	. Implement a quick response shipment policy	. Achieve a *s%* shipment-fill-rate of within *t* hours of order

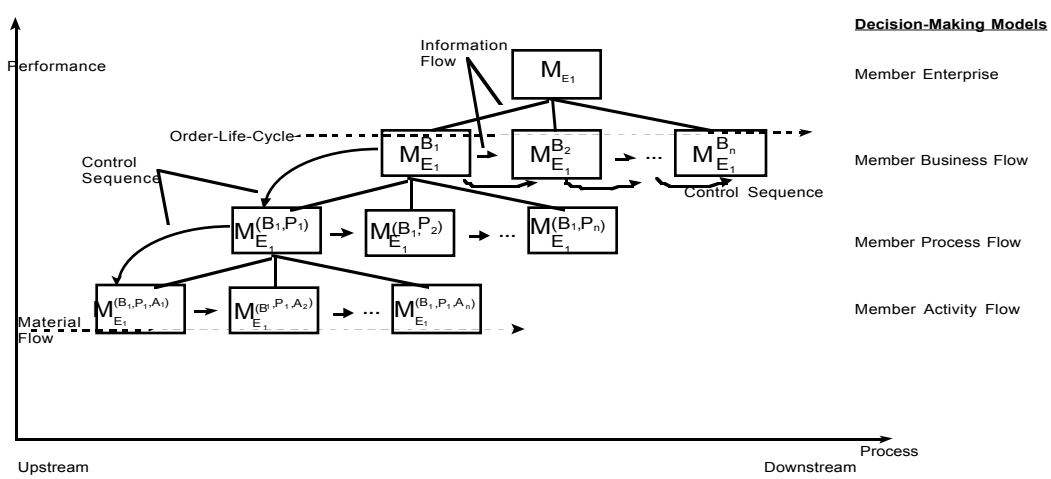


Figure 8. A Cooperative Supply-Chain Member Architecture

4.1.1.2 Cooperative Supply-Chain System: A Group Perspective

The organization of a Group in a CSC system has the purpose of finding common homogeneity in the heterogeneous behavior of supply-chain Members (Malone, 1990). This is accomplished by gaining mutual commitment, and converging on joint intentions of Members towards achieving common supply-chain goals. Some norms that enunciate this spirit of partnership are:

- allocation rules for sharing scarce resources in the supply-chain,
- rules for cooperation and coordination,
- adoption of a *problem-solving* approach by the Group,
- defining roles and responsibilities of each Member,
- rules for negotiation and compromise, and
- extent of *inter* and *intra* activity interactions in the Group.

System analysis of a Group deals with evaluating the influence of these factors on the Group enterprise. This is accomplished by, (a) conducting a value analysis of primary activities as depicted in Table 3, and (b) identifying hierarchy of controls in the decision-making process as depicted in Table 4 of the Group enterprise. This approach parallels the value analysis and control analysis activities performed earlier for supply-chain members.

Table 3. Group Enterprise Value Analysis

	Commitments	**Information Management**
Marketing & Sales	. Price agreements	. Share forecast demand and sales . Share product performance . Share product cost data
Inbound Logistics (*Receiving, Warehousing, Inventory Control, Production Planning*)	. Agreement on inventory stock levels . Pre-commitments on short and long-term manufacturing capacity	. Share production forecasts and plans . Share production schedules . Share inventory status . Reserve manufacturing capacity for specific products
Plant Operations (*Manufacturing, Inspection, Product Assembly, Product Packaging*)	. Pre-shipment inspections	. Share product and process specifications
Outbound Logistics (*Warehousing, Inventory Control, Shipping*)	. Warehousing agreements on finished goods . Direct shipments from manufacturing locations	. Share inventory status . Share customer order information
Service (*Organization and Management*)	. Guarantee delivery schedules	. Share forecast demand . Share forecast production schedules

Table 4. Group Enterprise Hierarchy of Controls

	Objective(s)	**Policy(ies)**	**Goal(s)**
Marketing	. Maximize customer service	. Evaluate and implement a *Push* or *Pull* policy	. Achieve an industry benchmark of *x%* order-fill-rate of within *t* days order processing
Production Planning	. Maximize production under-runs . Maximize inventory turns	. Evaluate and implement a JIT scheduling or planned production scheduling policy	. Achieve a *y%* effective capacity utilization . Achieve inventory of *k* or above
Plant Operations	. Minimize manufacturing costs . Maximize yield per production run	. Evaluate and implement a JIT manufacturing or planned manufacturing policy	. Achieve over *z%* actual capacity utilization . Achieve less than *r%* rejects

Figure 9 illustrates the architecture of a CSC Group enterprise. The integration of design components described in Section 4.1.1, is evident in this diagram. Decision-making models are aggregated from the lowest (Member business) to the highest (Group) component of the enterprise. The transformation in the order-life-cycle occurs at the Member business level as the order is processed, for example, by marketing & sales function of Member enterprises, in the sequence they add value to the product. Controls are passed at both inter (between common business operations of Group and a Member along the model hierarchy) and intra (within business operations belonging to the same function) levels to implement common supply-chain goals, policies, and objectives.

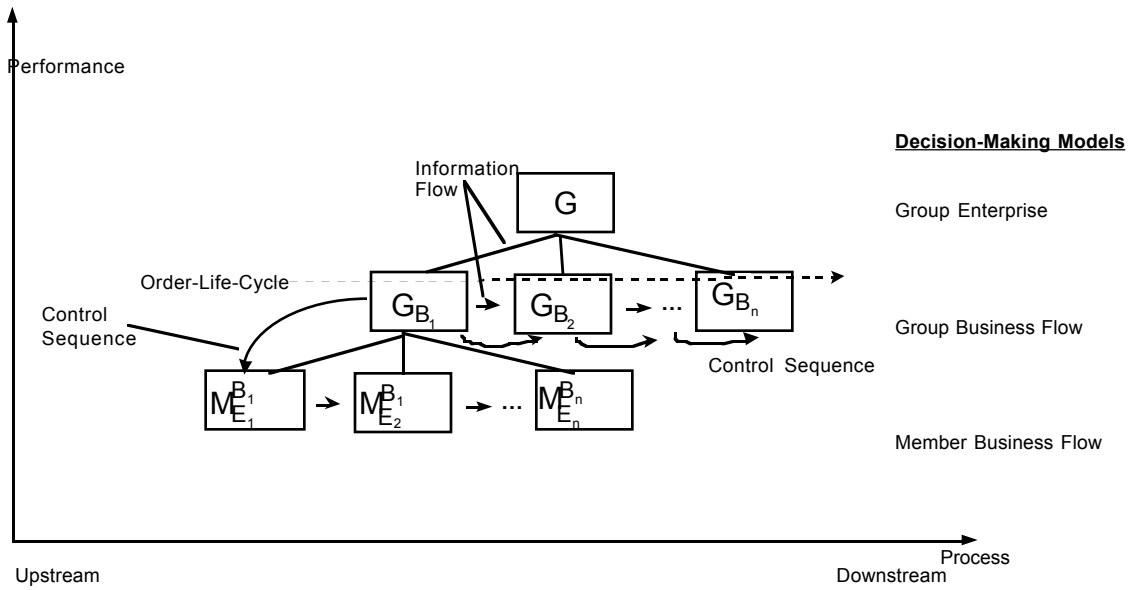


Figure 9. A Cooperative Supply-Chain Group Architecture

4.2 Cooperative Supply-Chain System Modeling

The main thrust of CSC modeling is based on the principle that its architecture should be domain independent, whereas its application is domain specific. Such a strategy assures integration of disparate applications to a common, yet generic architecture. Some guidelines for implementing this strategy are:

1. the structure of the conceptual model of a CSC system must accurately reflect inner workings of its global (Group) and local (Member) components,
2. the design of an application of CSC should be based on a conceptual model of the CSC architecture, but specific to decision-making relevant to that application,
3. realization of objectives of a CSC enterprise must be achieved through implementation of a highly coordinated set of strategies and policies at the global and local levels. These should be consistent with trends and directions pursued by the industry for which the supply-chain is being designed, and
4. the implementation of a CSC application model must balance the issue of scope vs. focus.

The goodness of a supply chain model for a problem, is judged by the ability of the problem solutions to satisfy necessary and sufficient conditions posed by the problem. That is,

- to satisfy *necessary conditions*, the CSC model must reflect requirements of the industry, as borne out of facts through various methods of inquiry, and
- to satisfy *sufficient conditions*, every business strategy that facilitates implementation of the CSC model, is a candidate solution to the industry supply-chain problem.

The above modeling concepts are further elaborated by two representations of a CSC system model:

I. *A Cooperative Supply-Chain System Decomposition Model* (DM) is depicted in part in Figure 4 with notations in the Appendix A (Taha, 1987). Initially an objective function is developed to identify how decision making across CSC may be formulated. The technology matrix D_j and corresponding resource vector b_j represent the independent *structure* of the Member. The technology matrix A_j and the objective function vector C_j denote the common structure of the Group derived from the homogeneity of Members. *Controls* embedded in the technology matrix constitute relationships between various strategies, such as identified in Table 2 (marketing, production planning, warehouse operations, etc.), in regards to their goals, policies, and objectives. These controls are propagated as constraint equations represented by the technology matrix. A similar approach is applicable for gathering Group information, per Table 4.

II. *A Cooperative Supply-Chain System Dynamic Process Flow Model* (DPFM), with notations in the Appendix B (Hillier and Lieberman, 1990). The *structure* of a Member is signified by the network depicted in Figure 10. This network has a source (supply) and a sink (demand) node with a transshipment node acting as an intermediary node. *Controls* in this network are implemented by modulating (managing discrepancies) inputs (activity flow rates) based on strategies identified in Table 2 (marketing, production planning, warehouse operations), to support goals, policies, and objectives. Linking of Member networks through common control strategies (Table 4), produces the *structure* for the Group.

For both models, coefficients for various decision variables in the technology matrix are derived by the application of various *optimization* techniques such as methods engineering and value engineering on different operations of the enterprise across the value-chain as

depicted in Table 1. A similar approach is applicable for gathering Group information, per Table 3.

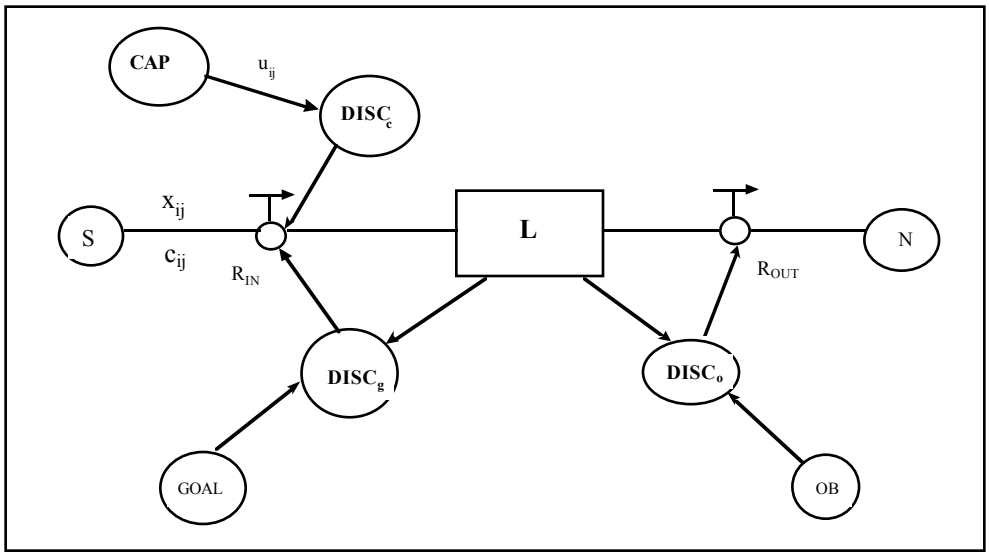


Figure 10. Illustration of a Cooperative Supply-Chain Dynamic Process Flow Model

4.3 Supply-Chain Analysis Methodology, Techniques and Tools

In this section, first a general description of the methodology is offered. Following this, various steps in the methodology are discussed. The methodology proposed below seeks to implement the CSC architecture described in Section 4.1 and depicted in Figures 8 and 9. A schematic of the supply-chain analysis methodology is offered in Figure 11.

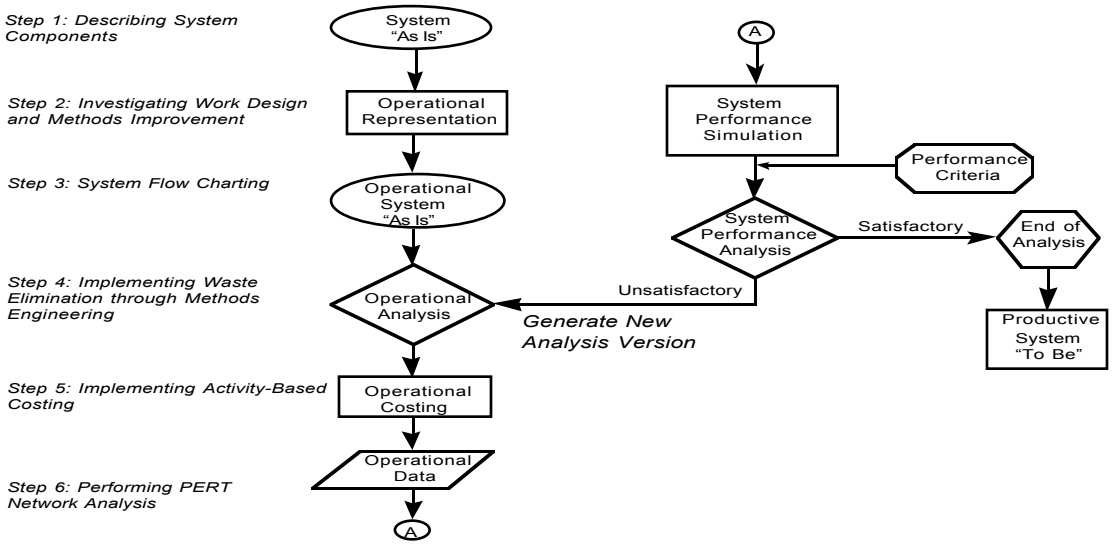


Figure 11. Supply-Chain System Analysis Methodology

A CSC is a collection of systems. Figure 12 depicts a generic system in the CSC.

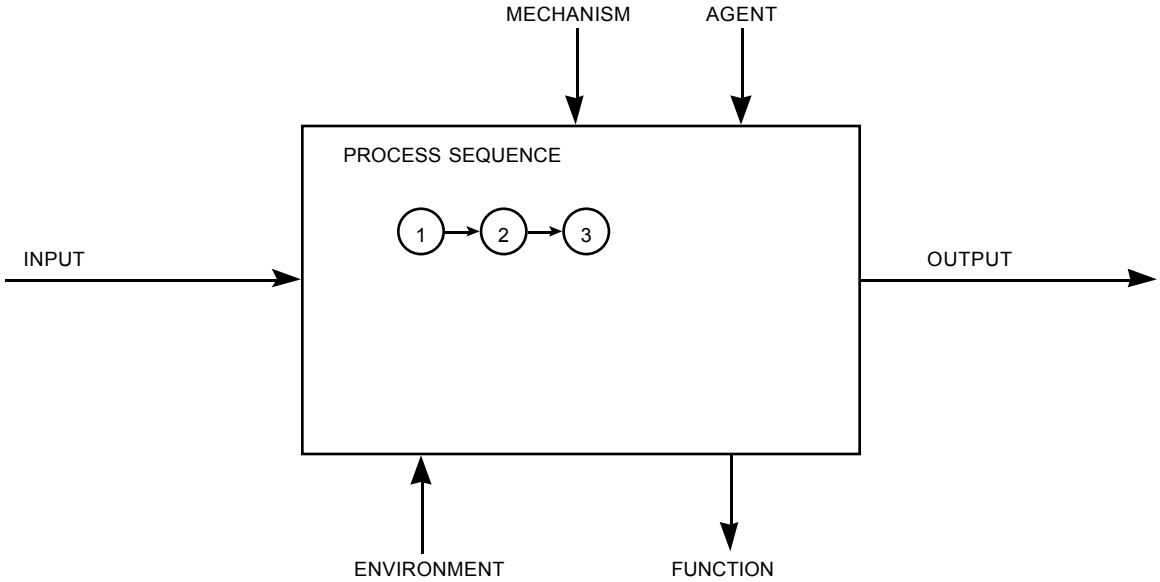


Figure 12. A Generic System Representation in a CSC

The elements of the generic system are described below (Nadler, 1970):

- *Input:* Any form of abstract or real technology – people resource, material, information, skill, service, and feedback from previous output into the system; on which processing will occur to generate an *output*.
- *Output:* Any form of abstract or real technology that results from processing of *input*s.
- *Process:* Denotes a transformation required to change an *input* into an *output*. A sequence of process(es) defines the exact order in which the conversion takes place.
- *Mechanism:* A physical or logical facilitator in the generation of an *output*.
- *Agent:* Resources that aid in transforming an *input* to an *output*.
- *Environment:* The setting under which the transformation takes place.
- *Function:* The goal(s) or results sought from the application of the system.

The components of CSC system – *structure*, *control* and *optimization* provide the basis on which a CSC architecture is built. The representation of these components in a CSC is achieved by associating and aggregating systems within a supply-chain enterprise.

The *association* of a CSC system(s) occurs in a Member or a Group setting. It provides means to define relationships between systems and their components at various levels of the enterprise. The value-chain analysis offers insights into workings and relationships within an enterprise. It is a way to model enterprise activities as they add value to a product. The modeling of activities occurs within their natural process streams. Process streams map the life cycle of an order against which products are being manufactured. Since a Member and a Group system have different characteristics, the level of detail at which analysis is conducted, is of course different.

Aggregation of CSC systems provides means to, a) create a structure within a Member or a Group, and b) enforce controls for the enterprise to function cohesively towards achieving a common goal. Aggregation of systems is done at various levels, to aid decision making. As

such, decision models are built to facilitate decisions carried out in the enterprise. Decisions are made while performing activities in the enterprise. Corresponding to levels of decision models, activities are also aggregated to a process flow, operation flow, and business function flow levels. Embedded in decision models are controls to guide managing of various types of flows in the enterprise.

This methodology is implemented as follows:

Step 1: Describing System Components

In this step, the "current" supply-chain pipeline system is described as a collection of systems and related activities performed by its Members, in the delivery of the end-product (Figure 13).

A hierarchical system decomposition technique is used for this purpose. The decomposed enterprise appears as follows:

- The topmost layer represents information flow in the enterprise. The flow of information is transient to any layer below it.
- The next layer represents business flow in the enterprise. These are the main business functions.
- The following layer represents process flow in the enterprise. These are processes designed in the respective business functions.

Decomposition enables representing the enterprise at various levels of aggregation. In this manner it is easy to break down a complex problem into manageable problem-solving pieces. Figure 14 depicts a system representation of a process in the NJP.

Figure 13. Process Steps for Men's Nylon Supplex® Parka

The decomposition of NJP enterprise value-chain is accomplished by developing a) value analysis, and b) control elements matrices for each Member, as well as for the Group. Appendix C provides detailed matrices of enterprise value analysis for the Group and Member perspectives. Similarly, Appendix D provides detailed matrices of enterprise hierarchy of controls at the Group and Member levels. Principles relating to value analysis and hierarchy of controls were described in Sections 4.1.1.1 and 4.1.1.2. These textile industry facts were compiled from the information provided in *Men's Nylon Supplex Parka Product Team Report on Site Visits and Meetings* (EM&S, 1995) and the site visit reports contained in Appendix E.

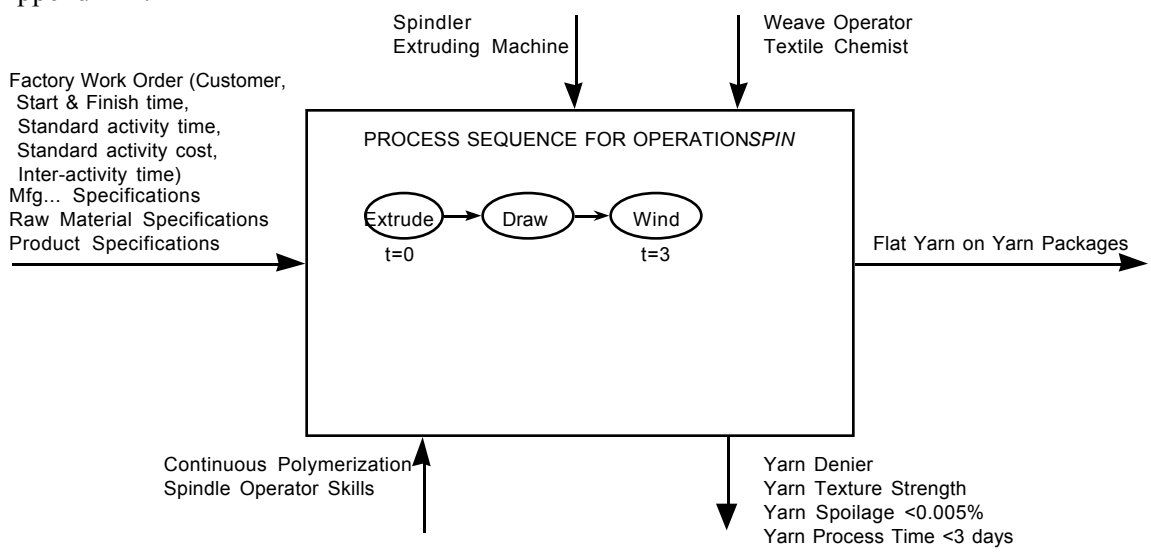


Figure 14. System Representation in a CSC

Step 2: Investigating Work Design and Methods Improvement

In this step of system analysis, relationships between methods, time standards, and costs on the operation of the enterprise are investigated. Primarily, this is done to understand the following relationships:

- Manufacturing methods to product costs,
- Standards to performance,
- Standards to quality,
- Standards to standard costs,
- Standards to scheduling,
- Influence of methods and processes on product designs, and
- Influence of methods and standards on how much work is to be done and how long it will take.

Figure 6 depicts these relationships pictorially. For the NJP, this step was not performed in much detail. However, the essence of standards and methods was carried on in describing various NJP system flows at different levels, as will be evident in Steps 3 and 4 described below.

Step 3: System Flow Charting

In this step of system analysis, the enterprise structure is aggregated or dis-aggregated at various levels of decomposition.

For example, at Level 0, the enterprise is decomposed into detailed activities, as shown in Figure 15 for the NJP.

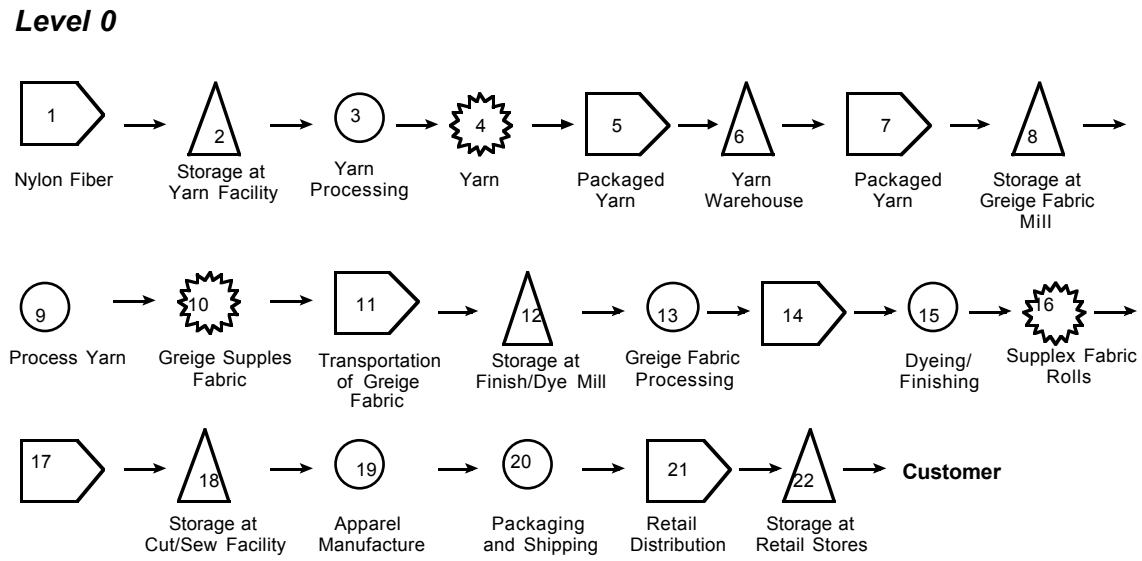


Figure 15. Activity Flow Representation of Men's Nylon Supplex® Jacket System

In this figure, activities are labeled as storage, processing, internal moves, transportation, setup, delay and inspection. Further, these activities can be classified as value-adding or non-value adding. By capturing associated standard times and costs (Appendix F), these activities can then be targeted for waste elimination through methods improvement techniques, as identified next in Step 4.

Similarly, the aggregation from Level 0 to Level 1 represents a process flow decomposition; from Level 1 to Level 2, an operation flow decomposition; and from Level 2 to Level 3 a business function flow decomposition. The flow of information at any of these levels is labeled as an information flow decomposition diagram.

Process Flow diagrams for Nylon Jacket Pipeline can be found in Appendix G. Business and Information Flows for Nylon Jacket Pipeline are enclosed in Appendix H.

Step 4: Implementing Waste Elimination Through Methods Engineering

System analysis in this step seeks to identify ways to eliminate any process that does not add value to the product. The approach adapted for this purpose is to first decompose the work content in the enterprise as depicted in Figure 3 for the NJP Group component and for the NJP Member components (Appendix I).

Next, a "5W and 1H" test is performed on that portion of work content in the system, on which methods improvement techniques are to be implemented. The following question set seeks to eliminate, combine, rearrange, and simplify activities.

5W's

- Why is this operation performed in this manner?
- What is the purpose of this operation?
- Who can best perform the operation?
- Where could the operation be performed better at lower cost or higher quality?
- When should the operation be performed in the overall process sequence?

1H

- How can the operation be performed better?

Process Charts for Methods Improvement for the NJP are enclosed in Appendix J. These charts identify processes that can be improved to add value to the product. However, these suggestions have not been implemented in this project.

Step 5: Implementing Activity-Based Costing

This system analysis step seeks to develop ability to trace costs to a particular product or customer that triggers various activities in the NJP.

The design of an activity-based costing model is approached in following phases:

Phase 1. Identifying Cost Hierarchies

In this phase, the origin and distribution of costs is established, using following hierarchies:

- Source of activity -- The source of activity in the NJP is, a) manufacturing, and b) delivering, the Nylon Jacket.
- Types of costs to be managed -- Directly tied to the source of activity cited above are, a) *product costs*, namely, procurement of raw materials, warehousing, production planning, and b) *marketing costs*, namely, customer service, order servicing, advertising and marketing.
- Activity Triggers -- These are the functions belonging to NJP Members where activities occur covering the entire product-life-cycle. For example, these functions include purchasing, receiving, warehousing, production, order entry, marketing & sales.
- Activity Centers -- As activities are performed to produce products, resources are consumed and cost drivers result. These are the drivers where the product consumes resources. For example, activity centers could be procurement, inspection, packaging, and shipping.

- Allocation of costs -- The allocation of costs is on the basis of cost pool(s) associated with an activity center. For example,

Activity Center	Cost Pool
Procurement	# of purchase orders
Receiving	# of receipts
Order Entry	# of customer orders
Quality Inspection	# of inspections
Sales & Marketing	# of sales calls
Production Control	# of releases
Inventory Control	# of inventory turns

- Allocation Level -- The level of allocation of costs is made on the basis of cost objects identified by each cost pool. For example,

Cost Pool	Cost Object
# of customer orders	orders
# of releases	batches
# of sales calls	customers
# of colors	SKU

Figure 16 depicts a bill-of-activity model outline for NJP system. It depicts the NJP enterprise decomposition into business functions, processes and activities.

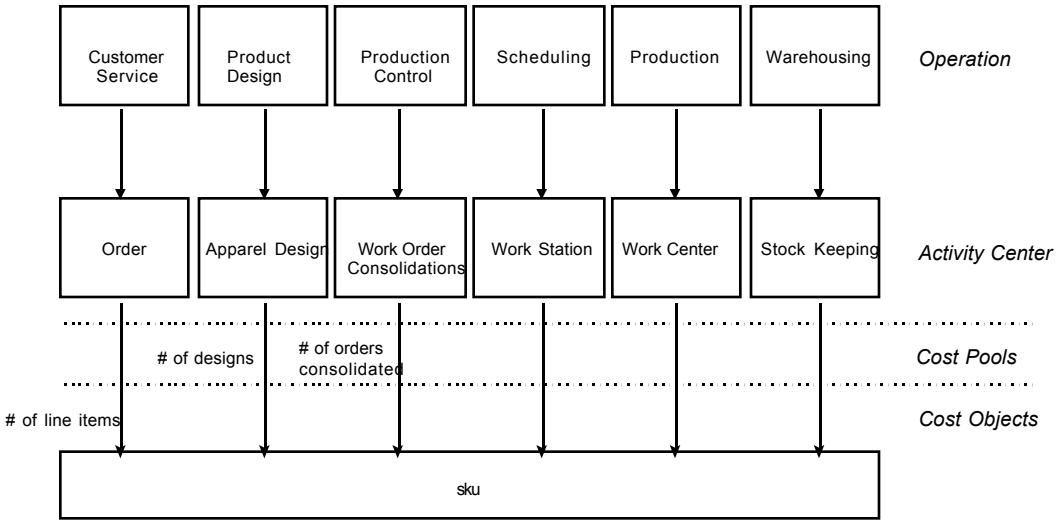


Figure 16. Bill of Activity Model Outline for Nylon Jacket Pipeline

Phase 2. Creating the Cost Database

Using cost hierarchies developed in Phase 1 and historic costs of the Member enterprises, a NJP pipeline cost database can be built.

Phase 3. Costing the Product

In this phase, activities identified in process flow charts in Step 3 of the methodology are mapped onto the bill-of-activity chart depicted in Figure 16. To maintain the cost database, it will be necessary to develop cost estimates for various throughput times, such as, setup time, queue time, storage time, process time, labor time, and storage time.

Activity-based costing calculations were not completed for the NJP analysis due to a lack of an appropriately detailed database.

Step 6: Performing PERT Network Analysis

Figure 17 depicts a network representation of interdependent activities in the NJP system. Since the objective of the analysis is to reduce completion time of the pipeline, a sound approach is to concentrate on the critical operation path for each of the constituent Members of the NJP. This will result in alleviating bottlenecks in the NJP.

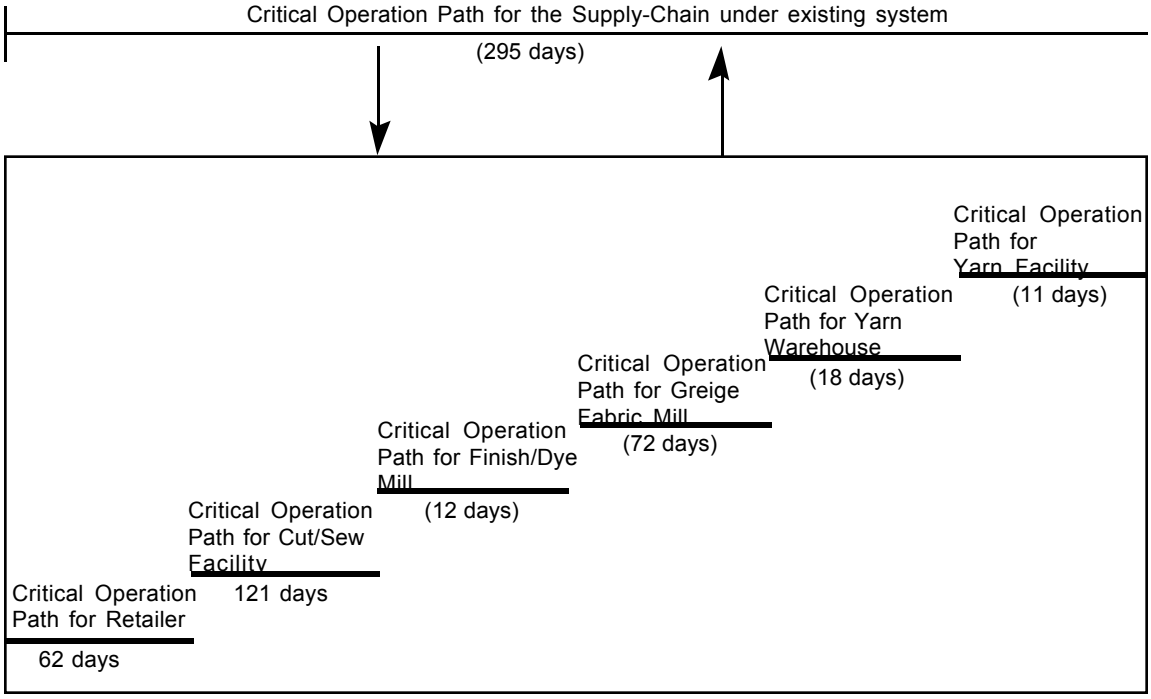


Figure 17. Network Diagram of the Nylon Jacket Pipeline Activities

5. Domain Specific Analysis of Findings

An analysis of activities in the NJP revealed that an outcome of lack of coordination in the supply-chain, is the *wait* between activities. Further classification of these activities, suggested that major contributors to *wait*, are the non-value added activities, namely, delay, setup, inspect, storage, and move/transport. In addition, a hierarchical breakdown of activities in the NJP system revealed that coordination of forecasts between supply-chain Members has the potential of improving customer service levels, as well as inventory levels and costs.

The analysis of NJP system was performed in both *static* and *dynamic* decision environments. For static analysis, the behavior of NJP was modeled for a time period, considered independently of future time periods. A forecasting model framework was developed and implemented using spreadsheet software. Only red color NJP demand data were used in the static analysis. For dynamic analysis, a continuous simulation model using off-the-shelf software was designed and implemented for several time periods, where the impact on other time periods of a decision made in one time period was explicitly considered. Only red and spruce colors NJP demand data were used in the dynamic analysis. In section 5.1, results of static analysis are discussed. Results of dynamic analysis are presented in section 5.2.

5.1 Nylon Jacket Pipeline Forecasting & Inventory Analysis

The objectives of NJP forecasting and inventory control analysis were defined as follows:

1. Modeling to maximize forecasting accuracy,
2. Analysis of inventory level and relevant costs, and
3. Analysis of the impact of service level and stockout probabilities on inventory levels.

These objectives were derived from relationships between forecasting error, inventory levels and associated costs, and customer service levels. The structured inventory management approach adapted for analysis of the NJP and depicted in Figure 18 incorporates these forms of relationships. The premise of this approach is as follows:

- The demand for a NJP assumes unique forms. These forms represent unique consumer behavior patterns,
- The selection of a forecasting model is based on its ability to closely predict a select subset of these behavior patterns accurately,
- Management of demand forecasts requires controlling forecast biases,
- Using forecasts to build inventories requires designing proper controls,
- Maintaining desired customer service levels and reducing stockouts, requires closer inventory management, and
- Finally, through experimentation with above techniques, a set of guidelines will emerge that can be adopted as NJP forecasting and inventory control standards.

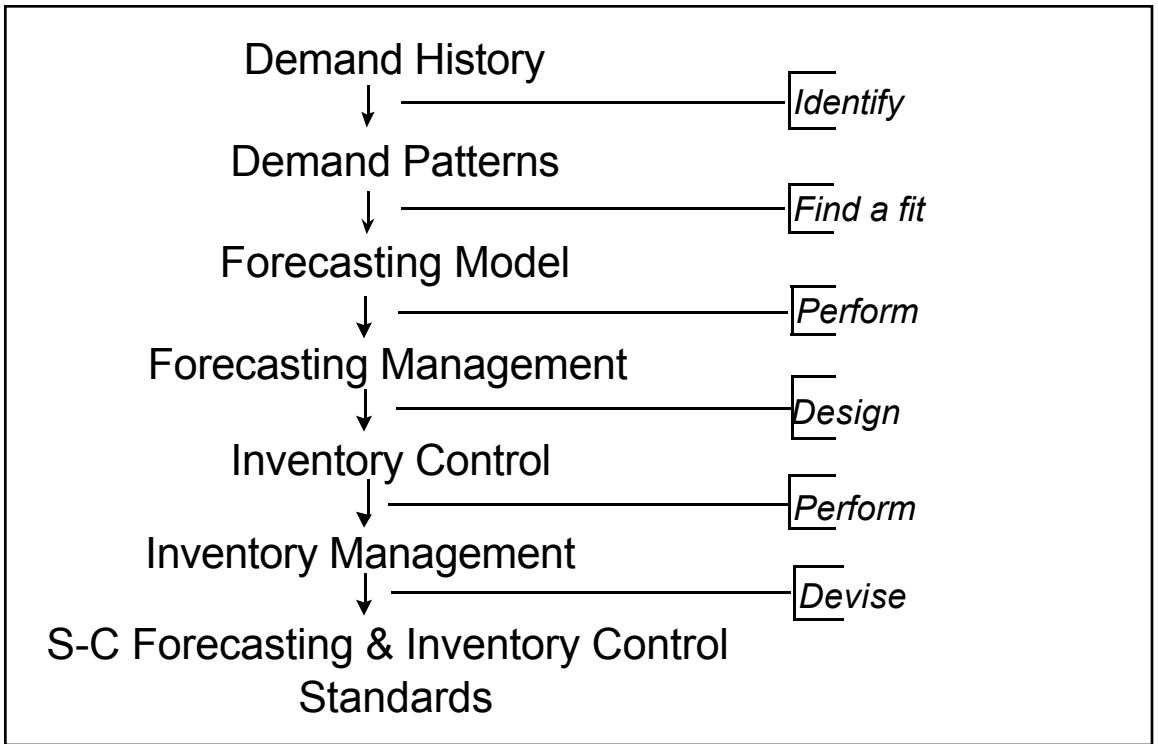


Figure 18. A Structured Inventory Management Approach for Nylon Jacket Pipeline Analysis

The principal criteria for evaluating forecasting models for NJP analysis was their ability to predict the behavior of demand movement. Figure 19 depicts typical demand movement forms of a catalog item. The 52-week forecast exhibits all four forms depicted in Figure 19, through the demand cycle. It shows random demand during periods when merchandise catalogs are being finalized. Cycles are exhibited at various times in the season. During holiday periods, strong seasonality is exhibited with trends mixed-in, off and on.

The results are discussed in the following order:

Section 5.1.1 describes the forecast modeling. Section 5.1.2 describes the forecast monitoring process. Section 5.1.3 deals with inventory control and application of inventory decision models to the NJP. Section 5.1.4 describes an approach to backward propagate demand. In section 5.1.5 inventory management is described. Finally, in section 5.1.6 general conclusions from the static analysis are discussed.

Results of static analysis of NJP demand and forecast are compiled under Appendix K.

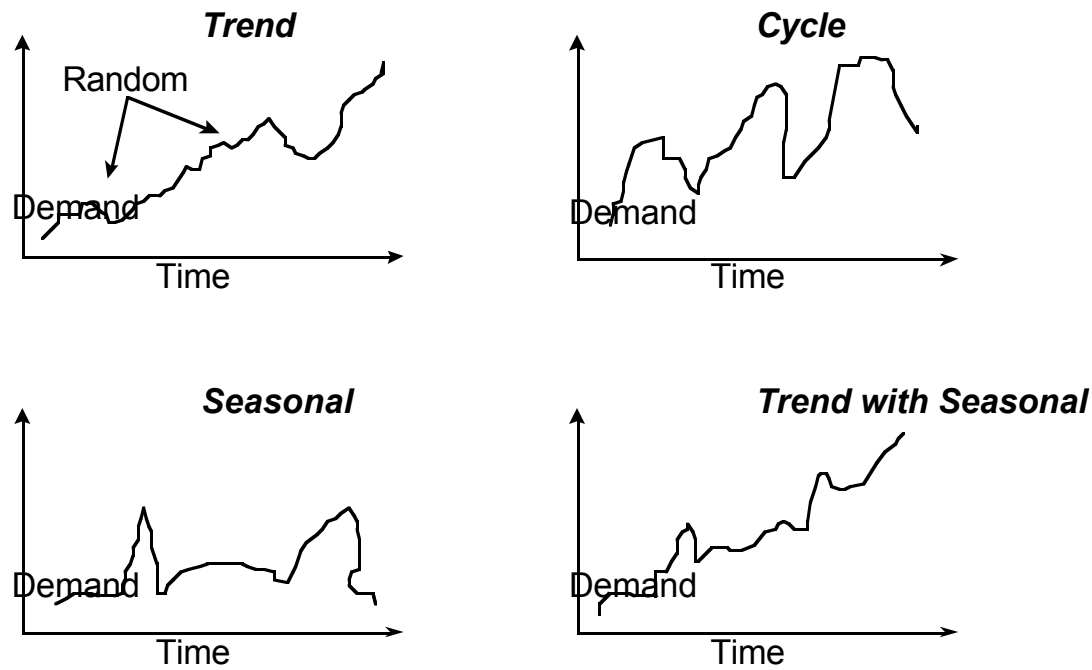


Figure 19. Forms of Forecast Movement in the Nylon Jacket Pipeline

5.1.1 Forecast Modeling

The most important objective of demand forecasting is to aid decision making for acquiring materials, utilizing capacity, and allocating other resources needed in the pipeline to synchronize production and delivery to/with consumer buying behavior patterns described in section 5.1. Accordingly, the models considered for evaluation are those that fit these demand behavior patterns. These are:

- Moving averages
- Trend
- Seasonal
- Seasonality with Trend

The following notation common to all forecasting models is introduced:

A – fixed cost component (insensitive to replenishment quantity), incurred with each replenishment, in dollars,
D_t - actual demand in period t.
DL - average demand during lead time. May not be the same as actual demand during period t.
D_{t-m} - actual demand in period (t-m), where (t-m) is a period, m period(s) prior to the current period t.
$D\bar{y}_t$ - average demand during period t.
e_t - forecasting error at time t.
$|e_t|$ - absolute value of forecasting error at time t.
f_t - forecast for period t.
F_t - exponential average at time t.
FP - forecasting period. Could be different than the actual demand period.

I_t - seasonality index for period t.
I_{t-m} - seasonality index in period (t-m), where (t-m) is a period, m period(s) prior to the current period t.
IN_t - level of inventory for a s.k.u. at time t, in units.
L - lead time period, in units of time t.
MA - moving average. Averages demand data from several of the most recent periods. Useful when demand data does not have rapid growth or seasonal characteristics. Also useful in removing random fluctuations.
MAD - mean absolute deviation from the forecasts, provides an average error in the forecast. A rule of thumb is to select the forecast with the least MAD.
n - total number of periods.
N – planning horizon, 1,2,…,
OP - order point – the point at which a s.k.u. should be ordered, in units per order.
Q – replenishment order quantity, in units.
r – carrying charge, the cost of having one dollar of a s.k.u. tied-up in inventory for a unit time interval, in dollar per dollar per unit time.
RSFE - a running sum of the forecast errors
SS - safety stock (or buffer) – additional quantity of a s.k.u. held in inventory, to be used in periods when demand for a s.k.u. is greater than its expected supply, in units.
SF - a measure that incorporates forecast error normalized to standard normal probabilities of service levels.
t - index for the current period, week.
T – time period, 1,2,…,t,
T_t - trend estimate at time t.
$T¥_t$ - average trend during period t.
TRCUT(T) – total relevant cost per unit time,
TS - a measure to monitor forecasting bias continually. A measurement to track the forecast trend in relation to the demand. The movement of tracking signal is compared to control limits. As long as the tracking signal is within these limits, the forecast is in control.
v – unit variable cost of a s.k.u., in dollars per unit.
α - exponential smoothing constant, $0 \le \alpha \le 1$.
β - trend adjustment constant, $0 \le \beta \le 1$.
γ - seasonality adjustment constant, $0 \le \gamma \le 1$.
σ - standard deviation (standard error) is used for computing the statistical control limits within which the forecast errors may lie.

I. Moving Averages Model

The Moving Average model enunciates a short-range forecast method that averages data from a few recent past periods to predict the forecast for the next period. It captures random variations in demand behavior, that is, movements in demand that do not follow a trend. The following relationship between demands and forecasts for consecutive periods are defined in this model:

$$MA_t = MA_{t-1} + (D_t - D_{t-n}) / n \qquad \ldots(1)$$

Results of analysis using this model are summarized below in Table 5.

Table 5. 1995 Red NJP Moving Average Forecast

Period	Actual Demand	3-period Moving Average	3-period Moving Average Forecast

(t)	(D_t)	(MA_t)	(f_t)
1	41		
2	31		
3	29	34	
4	16	25	34
5	13	19	25
6	11	13	19

The average at time t becomes the forecast for time t+1.
f_t is the most recently calculated moving average, $f_t = ma_{t-1}$.

Numerical Example:

The moving average forecast for period 5 is calculated as follows:

$$\begin{aligned} MA_5 &= MA_4 + (D_5 - D_{5-3}) / 3 \\ &= 25 + (13 - 31)/3 \\ &= 19 \end{aligned}$$

where, n = 3 week corresponds to the 3-week moving average.

II. Exponential Smoothing of Averages Model

An Exponential Smoothing model enunciates a short-range forecast method that takes the forecast for the previous period and adds an adjustment to obtain the forecast for the next period. The following relationship between demands and forecasts for consecutive periods are defined in this model:

$$F_t = F_{t-1} + \alpha(D_t - F_{t-1}) \qquad \ldots(2)$$

or $$F_t = \alpha D_t + (1-\alpha)F_{t-1} \qquad \ldots(2a)$$

Writing Equation 2a in terms of f_t,

$$F_t = \alpha D_t + (1-\alpha)f_t \qquad \ldots(2b)$$

$$\therefore \quad f_t = F_{t-1} \qquad \ldots(3)$$

Also,

$$e_t = D_t - f_t \qquad \ldots(4)$$

Results of analysis using this model are summarized below in Table 6.

Table 6. 1995 Red NJP Exponential Smoothing Average Forecast

Week (t)	Actual Demand (D_t)	Old Average (F_{t-1})	New Average (F_t)	Forecast (f_t)
0		0	0	
1	41	41	41	41
2	31	41	39	41
3	29	39	37	39
4	16	37	33	37
5	13	33	29	33
6	11	29	26	29

f_t is the most recently calculated exponential average, $f_t = F_{t-1}$.

Numerical Example:

The exponentially smoothed forecast for period 5 is calculated as follows:

$$\begin{aligned} F_5 &= \alpha D_4 + (1-\alpha)F_4 \\ &= .2 * 16 + .8 * 33 \\ &= 3.2 + 26.4 \\ &= 29.6 \text{ (rounded off to lower value 29)} \end{aligned}$$

where α=.2.

It may be noticed that the exponential average for period 5 (F_5), becomes the forecast for period 5 (f_5).

III. Trend Model

A Trend model enunciates a forecast method to capture a gradual, long-term up or down movement of demand. The following relationship between demands and forecasts for consecutive periods are defined in this model:

Trend estimation equation:

$$T_t = \beta(F_t - F_{t-1}) + (1-\beta)T_{t-1} \quad \ldots(5)$$

Trend adjusted exponentially smoothed average equation:

$$F_t = \alpha D_t + (1-\alpha)(F_{t-1} + T_{t-1}) \quad \ldots(6)$$

Trend adjusted forecast equation:

$$f_t = F_{t-1} + T_{t-1} \quad \ldots(7)$$

Forecast made at the end of period t for period (t + 1) is,

$$f_{t+1} = F_t + T_t \quad \ldots(8)$$

Results of analysis using this model are summarized below in Table 7.

Table 7. 1995 Red NJP Trend Adjusted Exponentially Smoothed Average Forecast

Period (t)	Actual Demand (D_t)	Exponential Average (F_t)	Trend (T_t)	Trend Adjusted Forecast (f_t)
		0	0	
1	41	41	0	41
2	31	41	0	41
3	29	39	-.4	39
4	16	37	-.72	36
5	13	33	-1.42	31
6	11	29	-1.92	27

Numerical Example:

The trend adjusted exponentially smoothed forecast for period 5 is calculated as follows:

$F_5 = \alpha D_4 + (1-\alpha)F_4$
$= .2 * 16 + .8 * 37$
$= 3.2 + 29.6$
$= 32.8$ (rounded off to 33)

$T_5 = \beta(F_5 - F_4) + (1-\beta)T_4$
$= .2(33-37) + .8 * (-.72)$
$= -.8 + -.576$
$= -1.376$ (due to rounding errors not exactly equal to -1.42, in the above table)

where α=.2 and β=.2

$\therefore\ f_5 = F_5 + T_5$
$= 32.8 - 1.376$
$= 31.424$ (rounded off to 31)

It may be noticed that the trend factor has removed the bias from the forecast by adjusting the forecast for positive or negative trends, as the case may be, period by period.

IV. Seasonality Model

A seasonality model enunciates a forecast method to capture an up-and-down repetitive movement in demand trend that occurs periodically. The following relationship between demands and forecasts for consecutive periods are defined in this model:

Trend estimation equation:

$$T_t = \beta(F_t - F_{t-1}) + (1-\beta)T_{t-1} \quad \ldots(9)$$

or $$T_{t+1} = \beta(F_{t+1} - F_t) + (1-\beta)T_t \quad \ldots(9a)$$

Trend and seasonality adjusted exponentially smoothed average equation:

$$F_t = \alpha(D_t / I_{t-m}) + (1-\alpha)(F_{t-1} + T_{t-1}) \quad \ldots(10)$$

or $$F_{t+1} = \alpha(D_{t+1} / I_{t+1-m}) + (1-\alpha)(F_t + T_t) \quad \ldots(10a)$$

Seasonality index equation:

$$I_t = \gamma(D_t / F_t) + (1-\gamma)I_{t-m} \quad \ldots(11)$$

Trend and seasonality adjusted forecast equation for forecast made at the end of period t for period (t + 1),

$$f_{t+1} = (F_{t+1} + T_{t+1}) * I_{t+1} \quad \ldots(12)$$

Results of analysis using this model are summarized below in Table 8.

Table 8. 1995 Red NJP Trend & Seasonality Adjusted Exponentially Smoothed Average Forecast

Period (t)	Actual Demand ($D_{t-33,94}$)	Seasonal Index ($I_{t-33,94}$)	Actual Demand ($D_{t,95}$)	Deseason-alized Demand ($D_{t,95}/I_{t-33,94}$)	Exponential Average (F_t)	Trend (T_t)	Seasonal Index ($I_{t,95}$)	Forecast (f_t)
					353	5.57		
20	95	.18	2	11	289	-8	.17	47
21	64	.12	15	126	250	-15	.12	27
22	153	.28	13	46	197	-22	.27	48
23	151	.28	31	110	162	-25	.28	38
24	174	.32	34	105	131	-26	.32	34
25	162	.3	22	73	99	27	.3	21
26	332	.62	54	87	75	-27	.62	30
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
52	45	.08	39	466	715	-2	.08	59

Numerical Example:

The trend and seasonality adjusted exponentially smoothed forecast for period 25 is calculated as follows:

The basis of adjustment of the forecast for seasonality is the demand for year 1994. First, a seasonality index for a period, m periods prior to the current period, is computed. Since,

there was no pattern to observe for periods (weeks) 1 to 19 of the year 1994, the forecast is truncated to include periods 20 to 52 (33 weeks).

$$I_{25\text{-}33,94} = D_{25,94} \div (\sum_{t=20}^{52} D_{t,94})$$
$$= 162 \div 537$$
$$= .3$$

$$F_{25} = \alpha * (D_{25,95} \div I_{25\text{-}33,94}) + (1-\alpha) * (F_{24} + T_{24})$$
$$= .2 * (22 \div .3) + .8 * (131 + (-26))$$
$$= (.2 * 73.06) + (.8 * 105)$$
$$= 14.67 + 84$$
$$= 98.67 \text{ (rounded off to 99)}$$

$$T_{25} = \beta(F_{25} - F_{24}) + (1-\beta)T_{24}$$
$$= .2(99 - 131) + (.8 * (-26))$$
$$= -6.4 + (-20.8)$$
$$= -27.2 \text{ (rounded off to -27)}$$

$$I_{25,95} = \gamma * (D_{25,95} \div F_{25,95}) + (1-\gamma) * (I_{25\text{-}33,94})$$
$$= .05 * (22 \div 99) + .95 * .3$$
$$= .011 + .285$$
$$= .296 \text{ (rounded off to .3)}$$

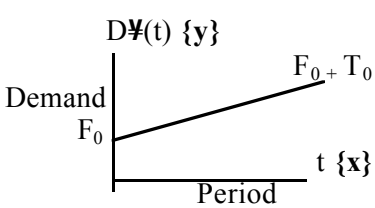
where α=.2, β=.2 and γ=.05

$$\therefore\ f_{25} = (F_{25} + T_{25}) * I_{25,95}$$
$$= (99 + (-27)) * .3$$
$$= 72 * .3$$
$$= 21.6 \text{ (rounded off to 21)}$$

For calculating the initial values for exponential average forecast (F_0) and trend (T_0), a simplifying assumption has been made to typify the relationship of 1994 demand w.r.t. time as linear. Stated another way,

$$D¥_{t,94} = F_0 + T¥_0$$

Pictorially,



where,

$$D¥_{t,94} = (\sum_{t=20}^{52} D_{t,94}) = 537$$

$$F_0 = 353$$

$$T¥_0 = D¥_{t,94} - F_0$$
$$= 537 - 353$$
$$= 184$$

$$\therefore \quad T_0 = 184 \div 33$$
$$= 5.57$$

and t = 33.

Rules for Selection of Smoothing constants α, β and γ:

The general rule-of-thumb is $0.01 \leq \alpha \leq 0.3$.

Rule for using a *lower* value - When the long run demand for product is relatively stable.

Rule for using a *higher* value - When the long run demand for product is relatively unstable (for example of sustained growth in sales). A higher value of $\alpha > 0.3$ may be justified, if the growth in sales is extremely high.

A similar approach is applicable for choosing values of β and γ.

5.1.2 Forecast Monitoring

The forecast monitoring of NJP is concerned with the accuracy of forecasts and controlling forecast biases.

I. Forecast Accuracy: The accuracy of forecasts is measured by Mean Absolute Deviation (MAD). MAD is the average, absolute difference between the forecast and demand. Stated in an expression,

$$\text{MAD} = \frac{\text{Sum of absolute values of forecast errors over a number of periods}}{\text{Number of periods}}$$

Stated quantitatively,

$$\text{MAD} = \sum_{t=1}^{n} |e_t| \ / \ n$$

Also for approximately normally distributed data,

$$\text{MAD} = .8\sigma, \text{ or } 1.25 \text{ MAD} = 1\sigma$$

As a rule of thumb, the range of MAD is between ±2 and ±5.

Table 9 offers comparison of MADs of fourteen forecasting methods applied to analyzing NJP pipeline problem.

Table 9. Comparison of MAD for Various Forecasting Methods used in NJP Analysis

Algorithm	Forecasting Method	Computed MAD
1	Bean's Method (base case)	42
2	Moving Averages - 3 period	40
3	Moving Averages - 6 period	53
4	Moving Averages - 9 period	58
5	Moving Averages - 12 period	67
6	Exponential Smoothing, α=.2	49
7	Exponential Smoothing, α=.7	33
8	Trend Adjusted Smoothing, α=.2, β=.2	46
9	Trend Adjusted Smoothing, α=.7, β=.2	31
10	Trend & Seasonality Adjusted Smoothing (33-period), α=.2, β=.2, γ=.05	92
11	Trend & Seasonality Adjusted Smoothing (33-period), α=.7, β=.2, γ=.05	24
12	Trend & Seasonality Adjusted Smoothing (52-period), α=.2, β=.2, γ=.05	46
13	Trend & Seasonality Adjusted Smoothing (52-period), α=.7, β=.2, γ=.05	20
14	Trend & Seasonality Adjusted Smoothing (52-period), α=.8, β=..05, γ=.7 (best case)	14

Criteria for selection of the best forecasting method is the one with the least value of computed MAD. Therefore, the trend and seasonality adjusted smoothing method with α=.8, β=..05, γ=.7 was selected among methods listed in Table 9, as the method for further comparative analysis:

Demand vs. Forecast -- Figures 20 and 21 are plots of demand and forecast for the red Nylon Jacket or the base and best cases respectively. Of the two models evaluated, the tight overlapping of demand and forecast plots in the best case example, provides a closer fit of forecast to demand for the planning horizon.

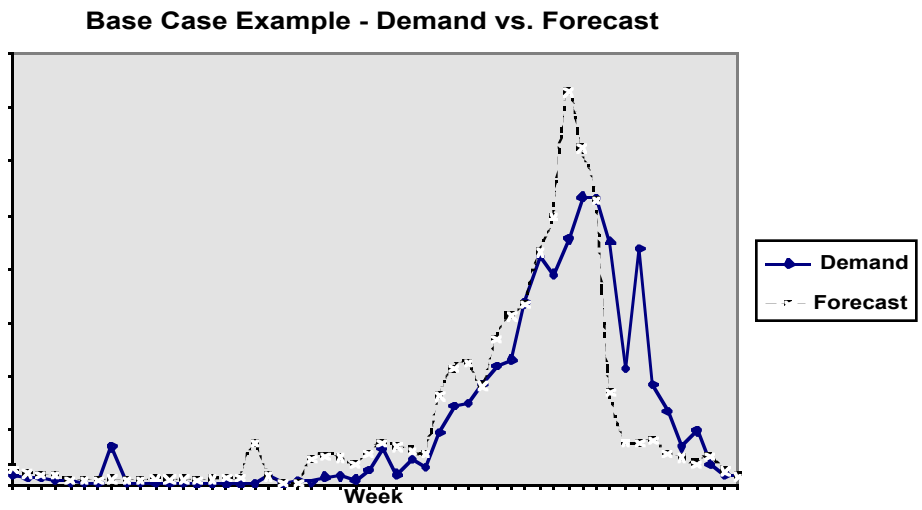


Figure 20. Base Case Demand and Forecast Plot

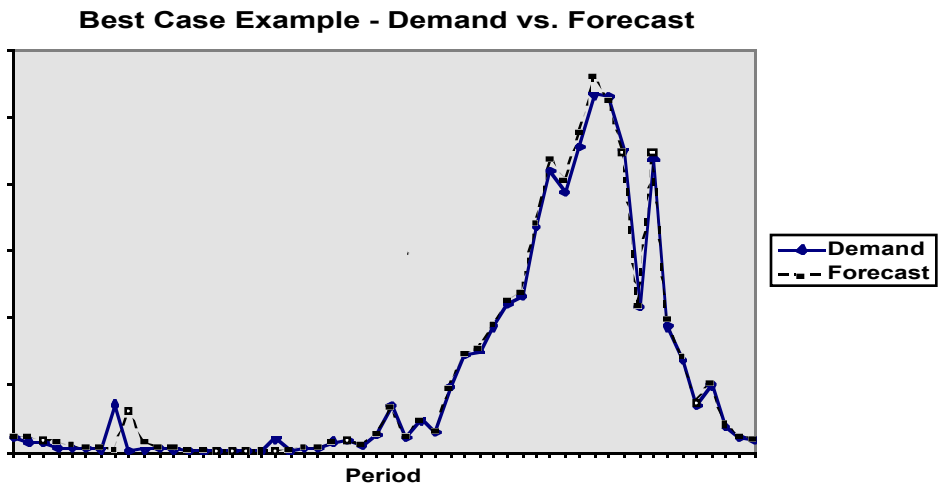


Figure 21. Best Case Demand and Forecast Plot

- Forecast Error -- A look at Figures 22 and 23 reveals that forecast errors generated using the best case model are much smaller and closely dispersed than those of the base case for the planning horizon.

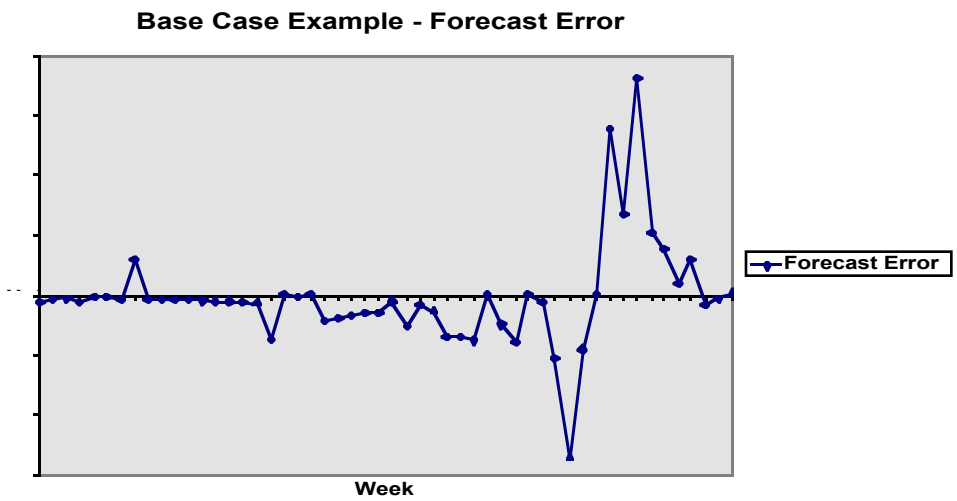


Figure 22. Base Case Forecast Error Plot

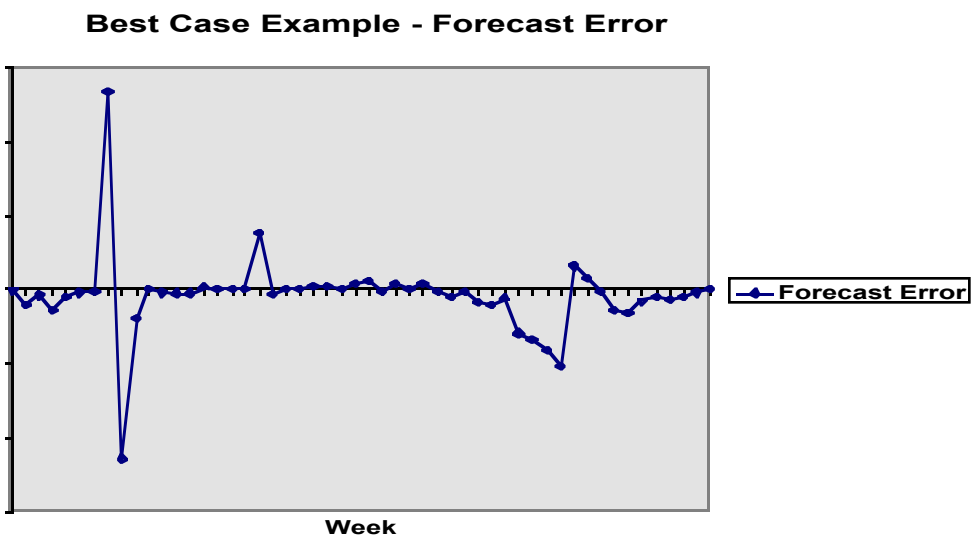


Figure 23. Best Case Forecast Error Plot

II. Forecast Control: is a way to monitor the forecast error over time to ensure that the forecast is performing correctly. In other words, the forecast is in control. Techniques used in the analysis are as follows:

- *Tracking Signal* indicates whether the forecast is consistently biased high or low. For example, a heavy downward dip in the tracking signal depicts a heavy bias towards higher forecasts. A comparative analysis of tracking signals presented in Figures 24 and 25 reveals that bias towards over forecasting in the base case is much more predominant than in the best case.

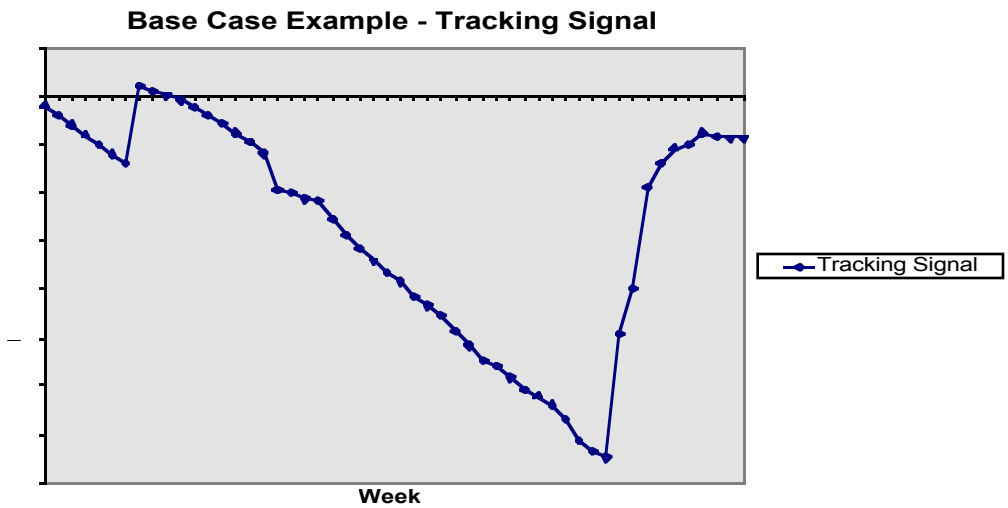


Figure 24. Base Case Tracking Signal Plot

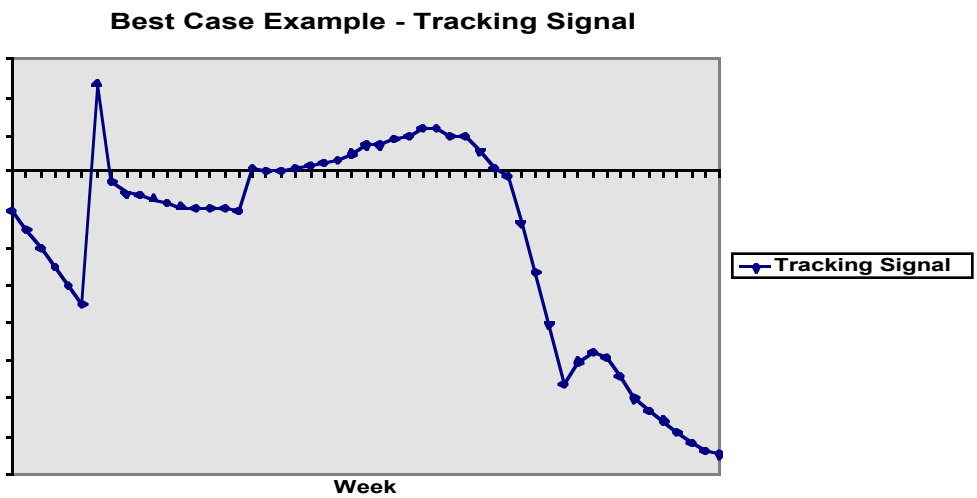


Figure 25. Best Case Tracking Signal Plot

- *Control Charts* provide visual means to track the behavior of demand within pre-defined control limits. Using the value of σ as 28, statistical control limits for forecast errors for trend and seasonality adjusted smoothing method with α=.8, β=..05, γ=.7, were computed. $\pm 3\sigma$ control limits, reflecting 99.75% of the forecast errors, give $\pm 3(28)$ or ± 84. The control chart presented in Figure 26 depicts this phenomenon in the NJP analysis case. The standard deviation, σ, also called the standard error, is computed as follows:

$$\sigma = \sqrt{(\sum(D_t - f_t)^2 \div (n-1))}$$

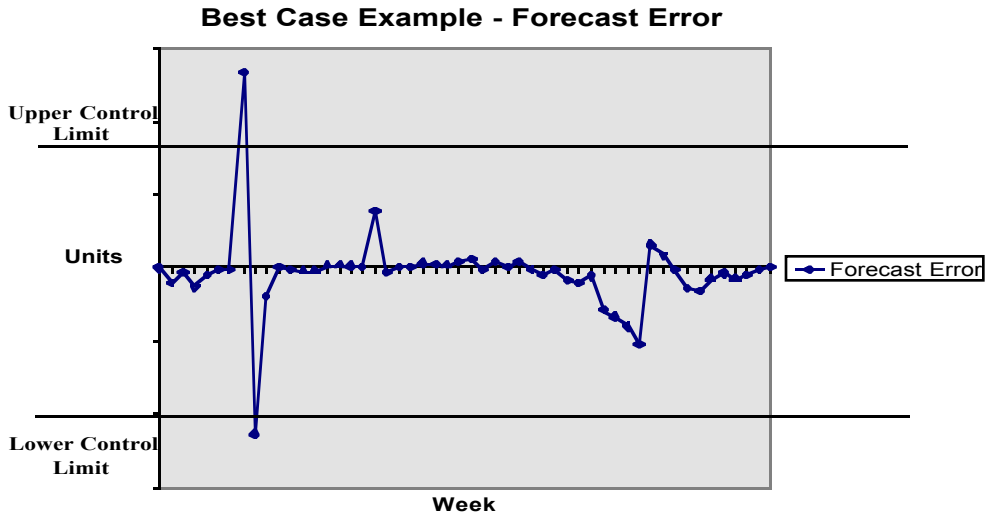


Figure 26. Best Case Control Chart for Forecast Errors

5.1.3 Inventory Control

Inventory control for the NJP system required application of inventory decision rules for demand with a predominantly seasonal trend patterns. Therefore, an inventory decision rule model for the case of significantly time-varying demand was implemented. In this case, the decision-makers must decide upon the replenishment quantity when the demand rate is deterministic and significantly varies with time. The model is described below.

Assumptions:

- s.k.u.'s have a seasonal demand pattern,
- s.k.u.'s have known trends in demand and these trends are expected to continue,
- multi-echelon production (or assembly) operations exploded through their production (or assembly) stages, have requirements that vary with time,
- demand may vary significantly from one period to the next significantly, but it is known,
- unit variable cost does not depend on the replenishment quantity,
- cost factors do not change appreciably with time,
- s.k.u.'s are treated independently of other s.k.u.'s,
- replenishment lead time is known with certainty so that delivery can be timed to arrive at the beginning of a period, and
- the entire order quantity is delivered at the same time (partial receipts are not considered).

Deriving Economic Order Quantity:

The criterion for determining appropriate order quantity is, minimization of costs. Costs considered in this model are:

- Fixed cost,
- Total inventory carrying costs to the end of period T.

The order quantity is derived as follows:

$$Q = \sum_{t=1}^{T} D_t$$

A value of T that minimizes the total relevant costs of replenishment and carrying of inventory is selected by a procedure described in the numerical example.

Numerical Example:

The forecasted demand pattern for L. L. Bean depicts a typical case, where the Red Nylon Jacket has a seasonal demand cycle. It is assumed that the unit variable cost of jacket is $1/unit/period and the fixed cost per replenishment $10. Further, the carrying cost of jacket in inventory is assumed to be $.014/unit/period, where, the assumed cost of money is 8%.

Projected forecast demand for Nylon Jacket during 1995 listed in Table 10 was used for the analysis.

Table 10. Projected Forecast Demand for Red Nylon Jacket during 1995

Period	1	2	3	4	5	6	7	8	9	10
Forecasted Requirements (D_t)	41	41	33	29	18	13	10	8	120	27

The decision rule is to evaluate TRCUT(T) for increasing values of T until, for the first time,

$$TRCUT(T + 1) > TRCUT(T)$$

In this numerical example, we have,

TRCUT(1) = A/1 = $10/1 = $10
TRCUT(2) = {A + D(2)vr}/2
= [$10 + {41 units * $1/unit * $.014/unit}]/2
= $5.28
TRCUT(3) = {A + D(2)vr + 2D(3)vr}/3
= [$10 + {41 units * $1/unit * $.014/unit}
+ {2 * 33 units * $1/unit * $.014/unit}]/3
= $3.83
TRCUT(4) = {A + D(2)vr + 2D(3)vr + 3D(4)vr}/4
= [$10 + {41 units * $1/unit * $.014/unit}
+ {2 * 33 units * $1/unit * $.014/unit}
+ {3 * 29 units * $1/unit * $.014/unit}]/4
= $3.18

Similarly,

TRCUT(5) = $2.74
TRCUT(6) = $2.44
TRCUT(7) = $2.21
TRCUT(8) = $2.03
TRCUT(9) = $3.29
From the above,

TRCUT(9) > TRCUT(8) or \$3.29 > \$2.03

Therefore, a T value of 8 is selected and the associated replenishment quantity becomes,

$$\begin{aligned} Q &= D(1) + D(2) + D(3) + D(4) + D(5) + D(6) + D(7) + D(8) \\ &= 41 + 41 + 33 + 29 + 18 + 13 + 10 + 8 \\ &= 193 \text{ units} \end{aligned}$$

Next, to be evaluated,

TRCUT(10) and so on, in order to evaluate TRCUT for selecting a value of T for the second time.

5.1.3.1 Application of Inventory Decision Model

The application of inventory decisions rules described in the foregoing has been accomplished recognizing the relationship between Safety Stock (SS), Order Point (OP) and Inventory Levels (IN). A continuous order point, order quantity (OP,Q) system captures these relationships as depicted in Figure 27.

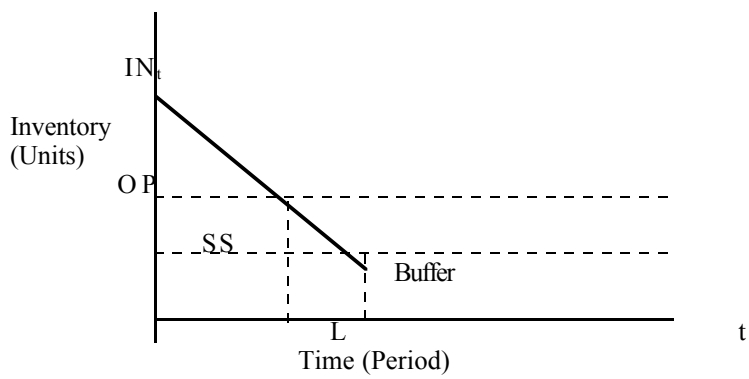


Figure 27. Relationship Between Inventory Levels and Stockouts

The decision on order point, order quantity, maximum inventory levels, and safety stock is dependent on the inventory policy implemented in the supply-chain network. Figure 28 depicts impact of these policies on the lead time in the supply-chain. The difference in lead times is obvious. A produce-to-order inventory policy is based on Just-In-Time (JIT) principles, whereby, replenishments are made when needed in the supply-chain. In contrast, a produce-to-stock inventory philosophy recommends building stocks for intermediate processes in order to meet varying service levels. It is, therefore, imperative that differences in inventory levels be recognized and planned for, while making inventory decisions for the NJP system.

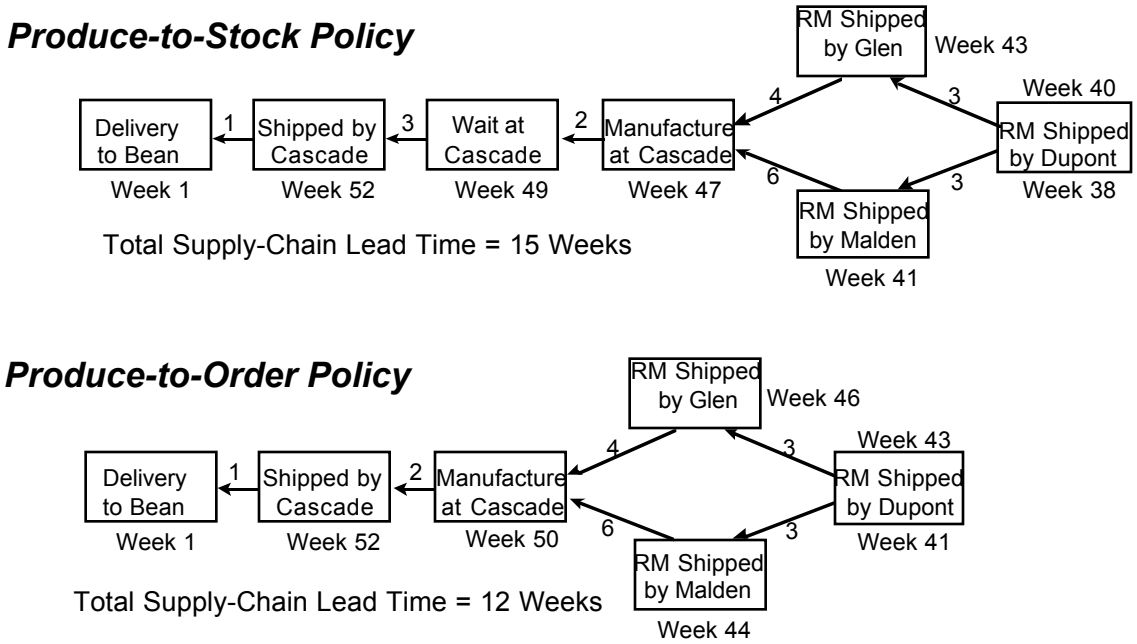


Figure 28. Supply-Chain Network in Relation to Inventory Policies

For a *purchase-to-order* inventory philosophy

$$OP = \sum_{t=1}^{T} D_t$$

For a *purchase-to-stock* inventory philosophy

$$OP = DL + SS$$

where,

$$SS = MAD * SF * \sqrt{(L/FP)}$$

where, safety factor (SF) is derived from Table 11.

Table 11. Relationship Between Service Levels and Stockouts

Service Level	Z_δ	Safety Factor (SF) ($1.25 * Z_\delta$)	Probability of a Stockout
.9	1.28	1.6	.1
.95	1.65	2.06	.05
.98	2.05	2.56	.02
.99	2.33	2.91	.01
.9986	3	3.75	.0014
.9999	4	5	.0001

Deriving OP in the case of the inventory decision models presented earlier is illustrated, with following examples:

Case 1. *Purchase-to-order* inventory philosophy:

$$OP(1) = D(1) + D(2) + D(3) + D(4) + D(5) + D(6) + D(7) + D(8)$$
$$= 41 + 41 + 33 + 29 + 18 + 13 + 10 + 8$$
$$= 193 \text{ units}$$

Case 2. *Purchase-to-stock* inventory philosophy

$$OP(1) = DL + SS$$
$$= 32 + 13$$
$$= 45 \text{ units}$$

where,

$$DL = 192 \text{ units} / 6 \text{ periods} = 32 \text{ units}$$
$$SS = 7 * 2.06 * \sqrt{(6/8)} = 13 \text{ units}$$

In this computation,

MAD = 7 = Average of MAD of periods 1 to 8
Safety Factor at 95% service level is 2.06
Lead time is 6 weeks, and
Forecasting period is 8 weeks

The variation in OP in the two cases presented above explains the essence of the merchandising philosophies and the inventory levels required to implement them.

The maximum level of inventory for a produce-to-stock philosophy is computed as follows:

$$IN_t = SS + Q$$

$$IN_1 = 13 + 193 = 206 \text{ units}$$

5.1.4 Backward Propagation of Demand Forecasts

The forecasted demand data generated by various forecast models was used to propagate demand across the supply-chain. That is, the forecast generated at retail is used as input for creating forecast at apparel, and so on. Forecasts were propagated using nominal lead time through the network to implement a produce (purchase)-to-stock and produce (purchase)-to-order inventory policies.

5.1.5 Inventory Management

Improved forecasting accuracy significantly enhances chances of realizing reduction in inventory costs. Figure 29 depicts this relationship. Thus, as forecast error decreases, inventory costs decline correspondingly.

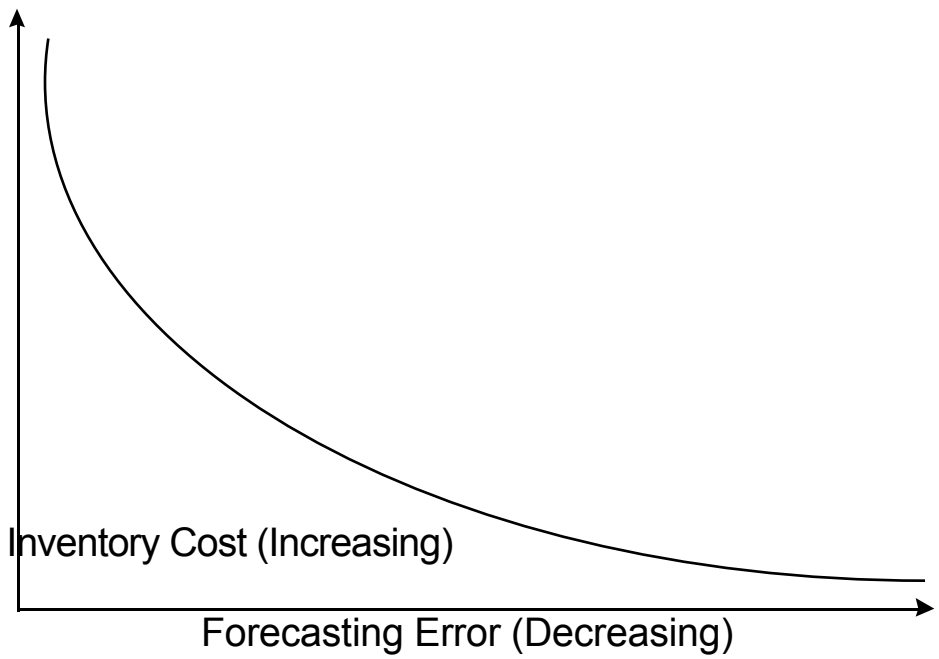


Figure 29. Relationship Between Forecasting Accuracy and Inventory Cost

Costs considered in the inventory model are as follows:

- Set-up cost – cost associated with ordering a replenishment
- Holding cost – cost associated with carrying inventory in stock
- Penalty cost – cost associated with a stockout (includes both cost of back-order as well as opportunity cost associated with lost sales)

Figure 30 depicts the relationship between inventory level and costs. A good inventory decision model derives optimal inventory levels while minimizing total inventory costs. The NJP analysis supports this notion by evaluating each of the fourteen forecasting models based

on four different inventory management policies: one produce-to-stock policy and three produce-to-order policies, targeting 90, 95 and 98% service levels, i.e., each forecasting model was implemented four times through the different inventory management policies and evaluated based on cost. First, as suggested by data in Table 12, the best case with the least forecast error (MAD = 14) of the fourteen models evaluated, produced the lowest total inventory cost (as a percent of sales revenue). The "Low" and "High" categories in Table 12 indicate the range of costs resulting from the four inventory management policies for a particular forecasting model. Next, data in Table 13 again points to best case model with least forecast error, producing the highest inventory turns and lowest backorder levels of all models evaluated.

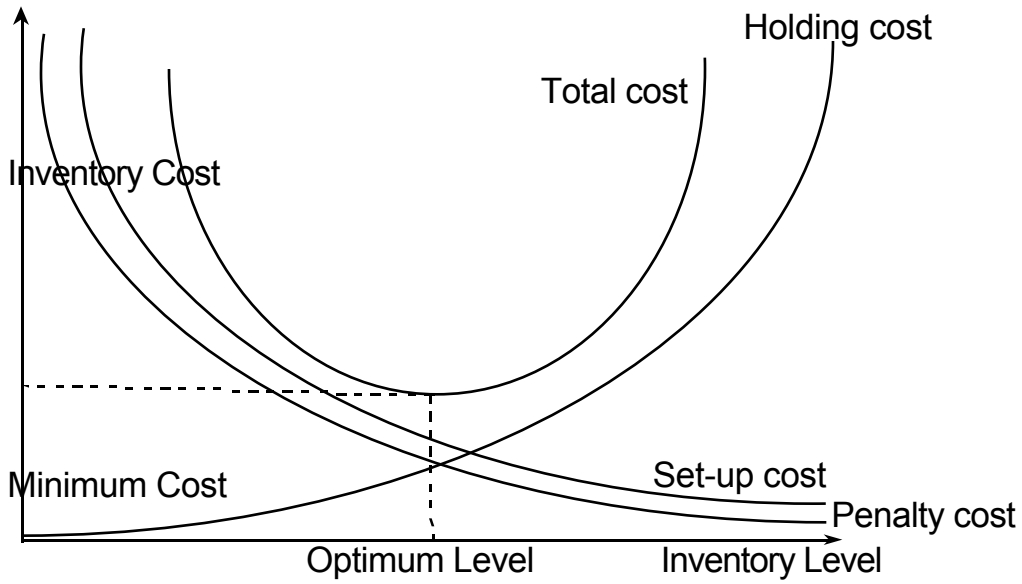


Figure 30. Relationship Between Inventory Level and Cost

Tables 13 to 16 offer comparative results of the base and best case for the retail, apparel, fiber, and the supply-chain (group).

Generally, a produce-to-order inventory policy results in a reduction of backorder costs, lower inventory carrying costs, and an increase in inventory turns in the supply-chain. In the retail sector, the best case model generates lower backorders, backorder cost, carrying cost and total inventory cost; and higher gross operating income and inventory turns, than the base case model.

Table 12. Costs in Relationship to Forecast Error

F.E. Index	Back Order Cost (% of Total Cost)		Carrying Cost (% of Total Cost)		Total Invty Cost (% of Sales Rev.)	
	Low	High	Low	High	Low	High
14 (*Best*)	.456	.785	.004	.022	49.031	51.156
20	.453	2.021	.003	.036	50.975	51.801
31	.571	5.692	.004	.074	51.055	53.818
33	.607	6.604	.007	.3	51.190	54.346
42 (*Base*)	1.655		1.276		51.578	
46	.714	12.567	.006	.237	51.213	58.054
46	.379	4.160	.011	.143	50.992	52.958
49	1.894	14.572	.029	.303	51.865	59.434

Table 13. Retail Sector Performance

Measure	Base Case	Best Case	
		Low	High
Back Order Cost (% of Total Cost)	1.276	.456	.785
Carrying Cost (% of Total Cost)	.326	.004	.022
Total Inventory Cost (% of Sales Revenue)	51.578	49.031	51.156
Gross Operating Income (% of Sales Revenue)	48.422	48.844	50.969
Inventory Turns	1.3	5.1	12.3
Back Orders (% of Units Sold)	2.881	1.005	1.731

Table 14. Apparel Sector Performance

Measure	Base Case	Best Case	
		Low	High
Back Order Cost (% of Total Cost)	0	0	0
Carrying Cost (% of Total Cost)	7	1.370	8.325
Total Inventory Cost (% of Sales Revenue)	70.668	66.733	71.690
Gross Operating Income (% of Sales Revenue)	29.332	28.310	33.267
Inventory Turns	.4	.4	1.5

Table 15. Fiber Sector Performance

Measure	Base Case	Best Case	
		Low	High
Back Order Cost (% of Total Cost)	0	0	0
Carrying Cost (% of Total Cost)	7.448	.587	7.448
Total Inventory Cost (% of Sales Revenue)	12.292	11.568	12.292
Gross Operating Income (% of Sales Revenue)	87.709	87.708	88.432

Table 16. Group Performance

Measure	Base Case	Best Case	
		Low	High
Back Order Cost (% of Total Cost)			
Retailer Contribution	100	100	100
Apprl. Mfr. Contribution	0	0	0
Fiber Mfr. Contribution	0	0	0
Carrying Cost (% of Total Cost)			
Retailer Contribution	6.127	.224	.424
Apprl. Mfr. Contribution	91.313	97.262	98.431
Fiber Mfr. Contribution	2.560	1.145	2.366
Total Inventory Cost (% of Total Supply-Chain Costs)			
Retailer Contribution	24.832	7.416	44.747
Apprl. Mfr. Contribution	73.087	53.551	90.352
Fiber Mfr. Contribution	2.081	1.702	2.232

In the apparel sector, the best case model generates lower carrying costs and total inventory costs and higher gross operating income for some of the inventory policies. However, for other inventory policies, the base case model faired better than the best case model. The cost burden for the apparel sector is much higher than the retail sector for all models evaluated. Similarly, the gross operating income is lower for apparel sector compared to that of the retail sector for all models. A logical explanation of this can be attributed to the fact that for produce-to-stock inventory policies in general and with higher customer service levels in particular, the wait time is comparatively much higher than other inventory policies.

In the fiber sector, the best case model fairs better for inventory stocking policies with lower customer service levels, in comparison to the base case model. However, the performance of the best case model is similar to that of the base case model when customer service levels are higher for inventory policies. These results could be attributed to the fact that in the case of the fiber sector, wait times between intermediate processes in the supply-chain were practically non-existent.

In analyzing the group performance data, it is noticed that in the case of the best case model, the apparel manufacturer's contribution to total supply-chain carrying costs is over 90%. The lowest contribution to this cost is by retailer. Similarly, there is an uneven distribution

of total inventory cost burden on the apparel manufacturer in favor of the retailer. These results point out the need for improving on wait times for inventory during intermediate processes so that one particular sector is not unduly penalized at the expense of another.

5.1.6 Static Analysis Conclusions

The conclusions of the analysis specific to red NJP pipeline are as follows:

- matching the forecast movement form to an appropriate forecasting model is essential to developing accurate forecasts,
- reducing forecast error is effective in improving pipeline performance,
- the forecast error has a domino effect on inventory levels and costs throughout the supply-chain,
- forecast models with high forecast accuracy improve supply-chain performance when replenishment schedules are coordinated with appropriate inventory policies throughout the supply-chain,
- there is a causal relationship between service level, lead time, inventory level and stockout probabilities, and
- it is apparent that the Apparel sector shares an unfair burden of inventory costs incurred by the supply-chain.

5.2 Dynamic Analysis

This section presents analysis findings of dynamic modeling of NJP system using continuous simulation. The section is organized as follows.

Section 5.2.1 describes benchmarking of the NJP supply-chain "as-is" system. A sub-model data sheet per Appendix L was used to map generic business functions as well as to describe simulation modeling variables, in each of the supply-chain sectors. Section 5.2.2 discusses results of NJP supply-chain sensitivity to lead time, forecast error, and comparative analysis of some of the forecast methods used for the static analysis, and described in section 5.1.1. Finally, in section 5.2.3 general conclusions from the NJP dynamic pipeline analysis are discussed.

5.2.1 Benchmark the Supply-chain Using Simulation Analysis

The purpose of the benchmarking activity is to establish the credibility of the simulation with respect to the analysis needs of the user. In benchmarking, both the real and simulated systems are considered to be black boxes with a set of inputs, I_r for the real system and I_s for the simulated system, and a set of outputs, O_r and O_s for real and simulated systems, respectively. Acknowledging that I_r cannot equal I_s, the condition that agreement exists on those input components deemed most important is used instead of equality. If this agreement measure is termed A, then $A(I_r , I_s) < \varepsilon$, where ε is determined by the user or analyst. In other words, the inputs are made to be as close as possible to each other. It is then desired that the outputs be close, within a specified tolerance. The outputs of the simulation are developed based on significant measures of real system attributes, so that O_r and O_s cannot be equal. Outputs agree if $A(O_r , O_s) < \tau$, where τ is specified in advance. If this agreement is

observed between the inputs and outputs, then the user can have more confidence that the simulation is emulating the real system to the tolerance of the user (τ) at least in the cases used for benchmarking.

In benchmarking the Nylon Jacket Pipeline simulation (NJPSim) the specified process could only be approximated. Due to inadequate data, the input vector for the real system was effectively unknown for many components, and the input vector for NJPSim was an approximation based on facts gleaned about the pipeline. As a result, the agreement between the input vectors could not be calculated. Similarly, but to a larger degree, the output vector of the real system was largely unknown (inventory levels, service levels, etc.). The only output measures made available to the analysis team were the approximate first service level at retail, the approximate second service level, the approximate lost sales level, and inventory turns. The simulation achieved service levels within 5% of the approximate levels given by retail.

Another element that can be brought to bear in establishing the credibility of a simulation is face validity. Face validation is the process of using informed experts to examine the conceptual background, execution, and output of a simulation model. The flavor of face validation is that the process is carried out relatively quickly. The expedience of face validation is often a plus in projects with tight timelines. Since the developers of NJPSim are relatively experienced in this class of models and simulation, they applied the face validation process to NJPSim. Although they had reservations about the long-term capabilities of the model (deterministic, not stochastic; no explicit representation of production scheduling; simplistic production logic; difficulty in representing more than one product; and focus of fidelity on retail), they deemed it appropriate for the type of scoping analyses to be performed.

Two cases were used for the benchmark activity: one used demand data from 1994-1995 for a red nylon jacket, and the other case used demand data from the same period for a spruce nylon jacket. In each case the simulation used production and lead time data that was identical, as well as demand forecasts provided by the retailer and target inventory levels derived from the retailer-supplied formula for “months forward coverage.” These cases were evaluated by the simulation and key outputs were compared. The key outputs were 1) first service level, e.g., the fraction of orders which were filled within the first service level time frame; 2) lost sales, the fraction of orders which could not be filled within a fixed time frame and were assumed to be lost sales due to excessive response time; 3) an estimate of profit per unit sold, this value is expressed as a fraction of the retail sales price; and 4) inventory turns, a measure of how rapidly the inventory flows through the system. The results of the two base cases are given in Figure 31 below.

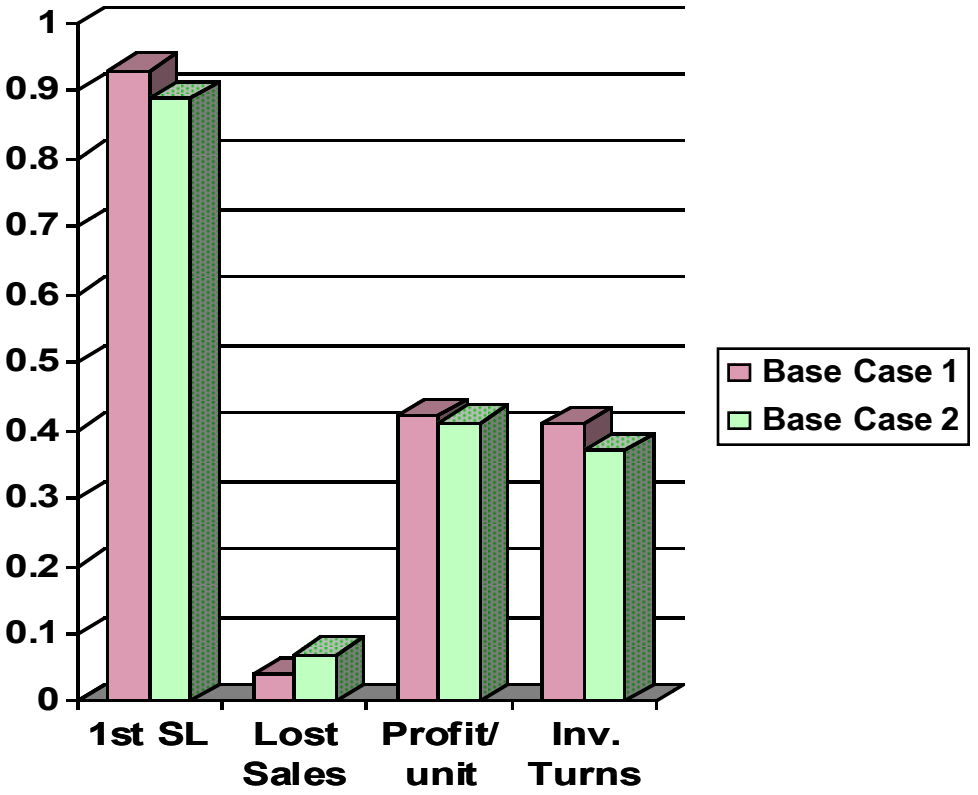


Figure 31. Comparison of Base Cases for Benchmark Process

5.2.2 Perform Supply-chain Sensitivity and Comparative Analyses

The dynamic analyses performed used NJPSim centered around two issues. The first issue is the question "How sensitive is performance of the supply-chain to retail lead time?" The second issue is "What is the influence of different forecast methods and consequent error (at retail) on the performance of the supply-chain?" As a consequence of answering these two questions, the analyst can also address the issue of which is better, reducing supply-chain lead time, or improving forecast capability for the products studied.

5.2.2.1 Supply-chain Sensitivity to Retail Lead Time

In examining the influence of lead time between the retailer and the apparel manufacturer, the two base cases were employed and the lead time was progressively reduced from 100% of the baseline to 50% and the resultant performance measures were noted. Comparative metrics are shown in Figure 32 for the red product and in Figure 33 for the spruce product.

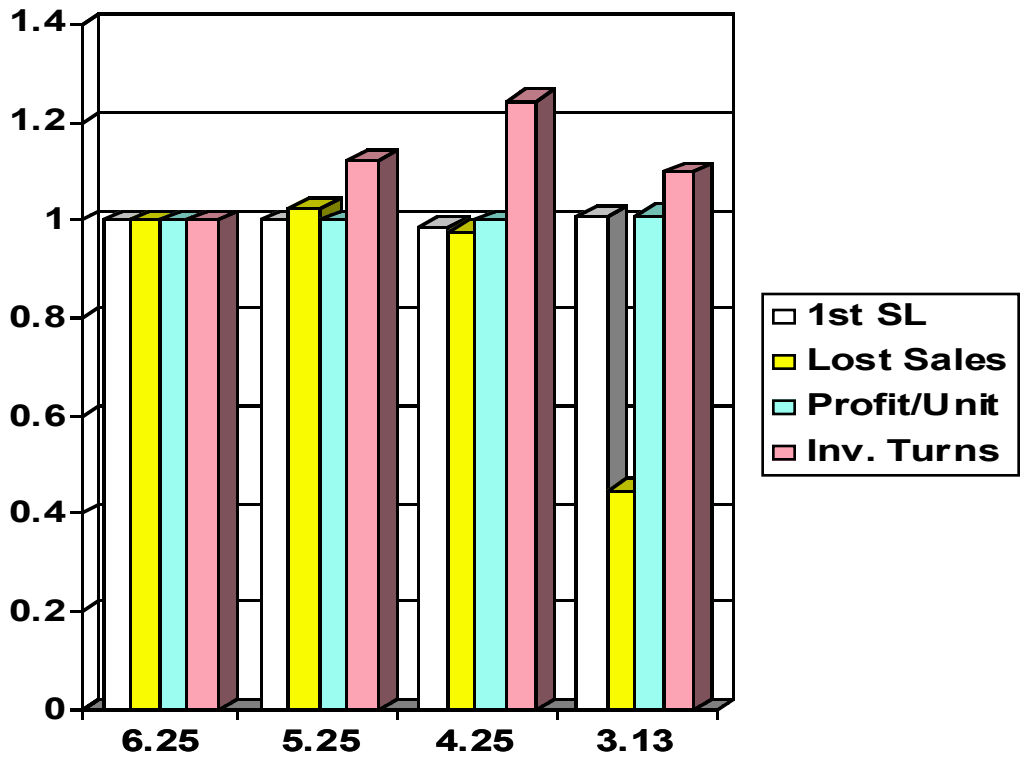


Figure 32. Comparison of Metrics Versus Lead Time (wks) for Red Product

All measures are made relative to the base case results for the red product, so for all measures, the values at 6.25 weeks lead time is normalized to 1.0. For the scenario where the lead time is 5.25 weeks, the simulation showed that the first service level was unchanged, lost sales increased mildly (2.5%), profitability is unchanged, and inventory turns increased about 12%. For the case where lead time is 4.25 weeks, the first service level drops about 2%, lost sales drop about 2.5%, profitability is unchanged, and inventory turns increase about 25%. For the case where lead time is cut in half, 3.125 weeks, the first service level increases 1%, lost sales decrease dramatically (55%), profit per unit increases 1%, and inventory turns are about 10% higher than the base case.

For the spruce product the method is the same. Recall that for the spruce scenario, a different demand stream is used, as is a different forecast and target inventory level. For all measures of pipeline performance, the values at 6.25 weeks lead time is normalized to 1.0, as performance is made relative to the spruce base case. For the scenario where the lead time is 5.25 weeks, the simulation showed that the first service level decreased mildly, about 2%, lost sales increased mildly (1.5%), profitability is slightly down, and inventory turns increased about 2%. For the case where lead time is 4.25 weeks, the first service level drops about 3%, lost sales increase about 11%, profitability declines about 1%, and inventory turns increase about 5%. For the case where lead time is cut in half, 3.125 weeks, the first service level decreases 2.5%, lost sales increase 7%, profit per unit decreases 0.6%, and inventory turns are about 16% higher than the base case.

To a large degree, this scenario suffers from a poor initial forecast. Since the target inventory level is derived from the initial forecast, it is sometimes the case that demand exceeds inventory, so that lost sales are incurred. Because the simulation has no short term forecast

correction for demand, shortening the lead time does not make the lost sales picture any better. However, if a credible short term correction for demand is allowed in the simulation, one would expect decreasing lead time to have a beneficial effect in reducing lost sales.

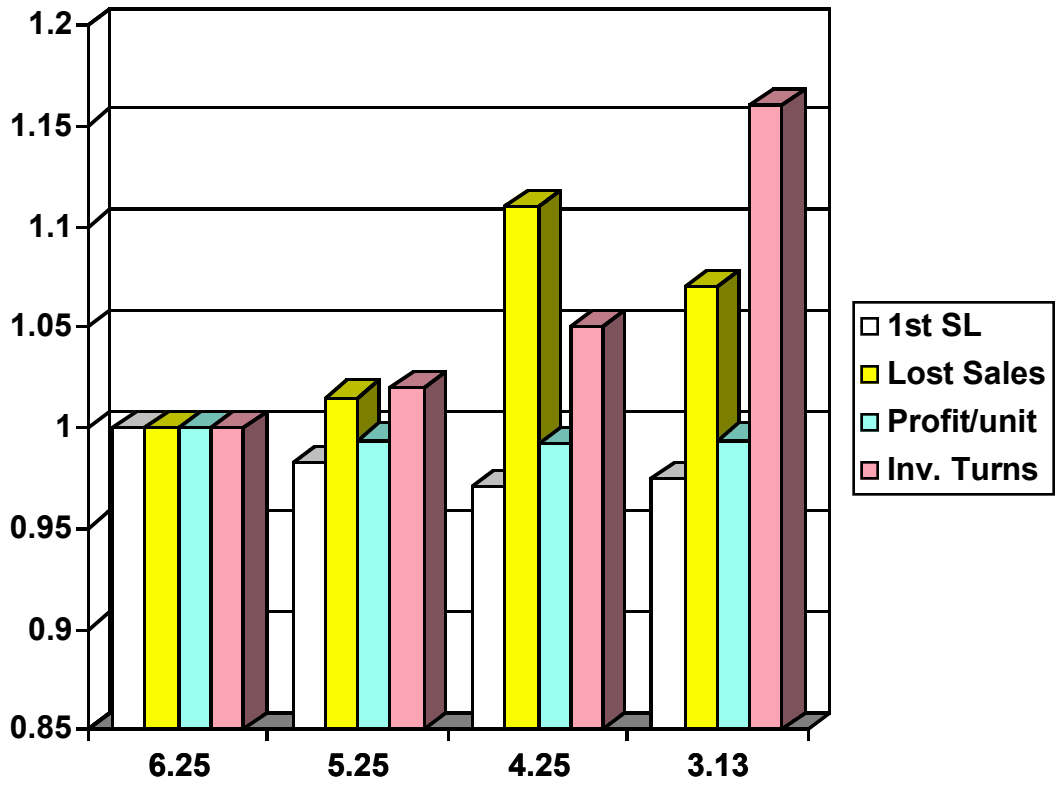


Figure 33. Comparison of Metrics Versus Lead Time (wks) for Spruce Product

5.2.2.2 Supply-chain Sensitivity to Forecast Error

The purpose of this investigation was to assess the influence of different forecast methods and their attendant errors on the performance of the pipeline. In Section 5.1.1, the alternate forecast models are described. In the analysis given here, only two forecast models are used in comparison with the base case for the red product. The forecast models are based on components for demand trends, seasonality, and with exponential smoothing of the demand data. Specifically, algorithm 12, from Table 9 in section 5.1.2, is a forecast model with weights $\alpha = 0.2$; $\beta = 0.2$; and $\gamma = 0.05$ and has a mean average deviation (MAD) of 46. The MAD is a quantitative measure of forecast error; the perfect forecast algorithm would have a MAD of zero. This algorithm is similar to the performance of the forecast algorithm used by the retailer. The alternative forecast model is the best case and is termed algorithm 14 and has weights $\alpha = 0.8$; $\beta = 0.05$; and $\gamma = 0.7$ with a MAD of 14. For each forecast model, a target inventory level is determined by specifying a safety stock inventory component required to meet a specified service level (90%, 95%, or 98%). As the service level increases, it is expected that the target inventory level will increase as well.

The relative performance of the red base case with respect to using the forecast method defined by algorithm 12 and the target inventory levels for the 90, 95, and 98 percent service rates is given in Figure 34. Again, the results for algorithm 12 are given only for 1995 demand data, while the metrics are compared to the base case for red which rely upon 1994-1995 data. Using algorithm 12 also has a dramatic effect on the pipeline metrics. First, as with algorithm 12, lost sales go to zero for all service levels. First service levels drop dramatically to 75% of the base case results. Lost sales more than double. Profit per unit declines to 94% of the base case. However, inventory turns increase nearly 500%. Clearly, using this algorithm implies markedly decreased performance for the pipeline.

The relative performance of the red base case with respect to using the forecast method defined by algorithm 14 and the target inventory levels for the 90, 95, and 98 percent service rates is given in Figure 35. Again, the results for algorithm 14 are given only for one year of demand data, while the metrics are compared to the base case for red which rely upon two years of data. Using algorithm 14 also has a dramatic effect on the pipeline metrics. First service levels drop dramatically to 75% of the base case results. Lost sales more than double. Profit per unit declines to 94% of the base case. However, inventory turns increase nearly 500%. Clearly, using this algorithm implies markedly decreased performance for the pipeline.

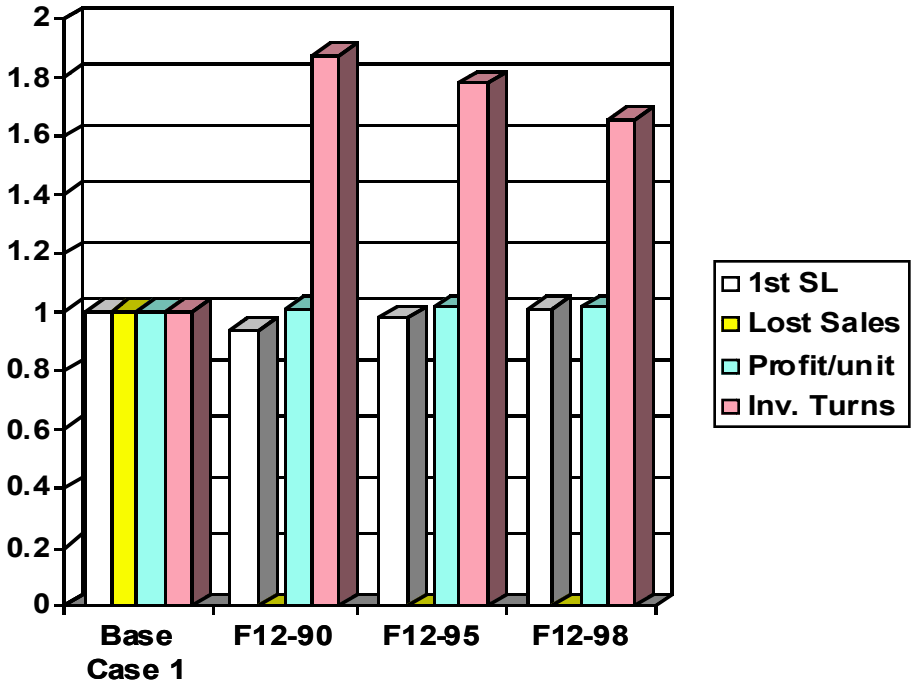


Figure 34. Performance of Algorithm 12 Compared to Red Base Case

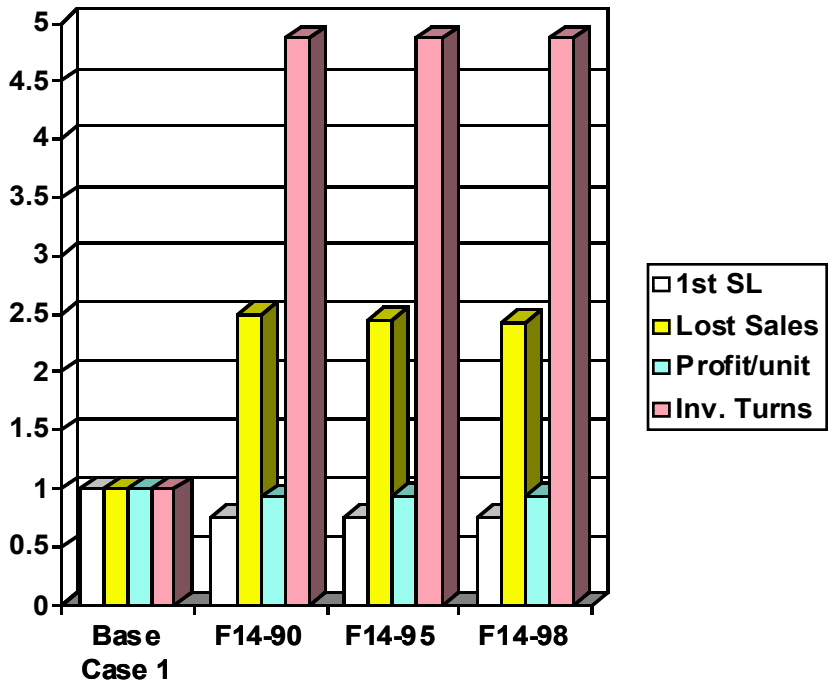


Figure 35. Performance of Algorithm 14 Compared to Red Base Case

The performance of algorithm 14 was a surprise to the analysis team which was expecting improved performance over algorithm 12. Inspection of the simulation output indicated that although the target inventory levels were adequate, small changes in timing could throw off the synchronization of the pipeline so that roughly 20% of the orders had to be shipped late, incurring extra administration costs and 5% turning into lost sales. The analysis team decided to investigate an alternate replenishment schedule that had been developed in the static analysis reported in section 5.1.1. The replenishment schedule was developed according to schemes that relied on economic order quantities. Without changing anything but the replenishment schedule for algorithm 14, the performance markedly improved, as shown in Figure 36. As can be seen, first service levels improve by 7%, while lost sales are zero. Profitability increases by 4% and inventory turns increase almost 500%. The lesson taken by the analysts was that reducing forecasting error alone does not indicate improved pipeline performance. It must be accompanied by an integrated replenishment schedule to assure performance enhancement.

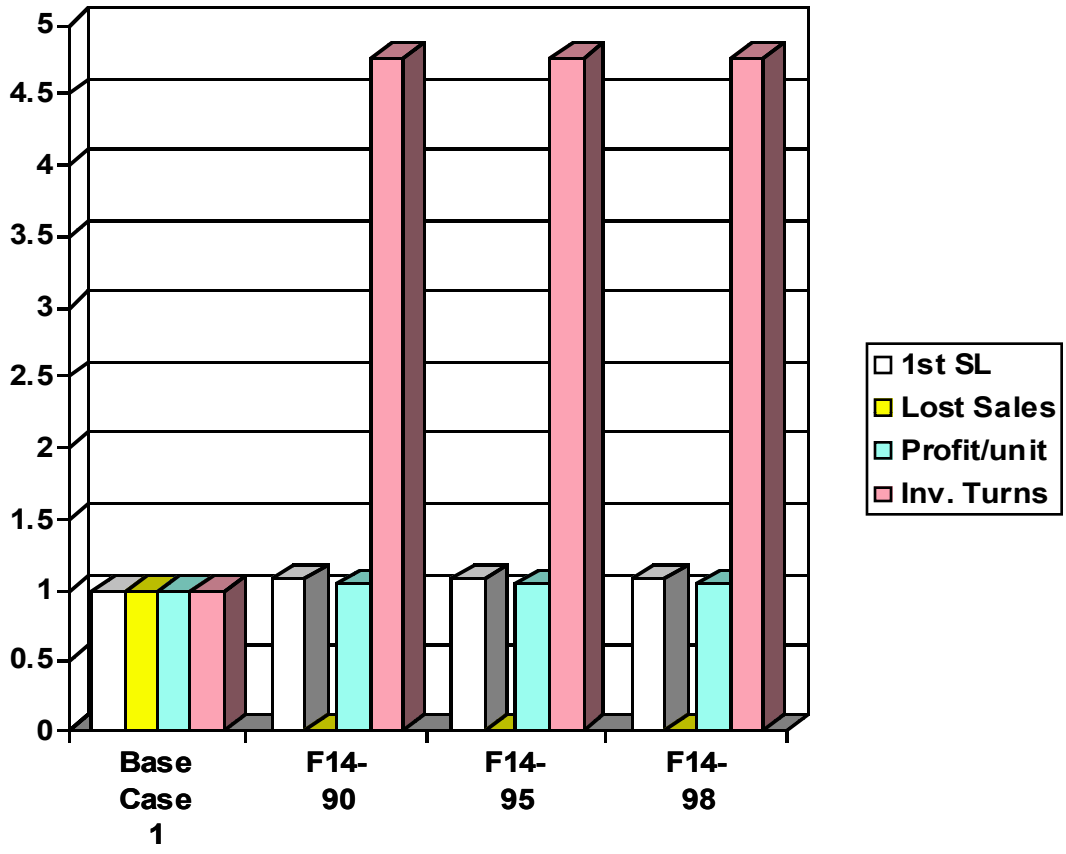


Figure 36. Performance of Algorithm 14 with Specific Replenishment Schedule Compare to Red Base Case

5.2.2.3 Comparative Analysis: Shortest Lead Time vs. Best Forecast

It is natural to contrast the scenarios in which sensitivity analysis has been performed. Which is better for a pipeline, to reduce lead time, or reduce forecasting error? To address this question the analysts compared the two scenarios in which the shortest lead time was evaluated and the best forecast error was demonstrated. Both of these scenarios are contrasted to the red base case, as shown in Figure 37.

It is difficult to make a case for any but the best forecast error case to be the superior performer, as it has the highest service level, the lowest lost sales, the highest profit/unit, and the highest inventory turns.

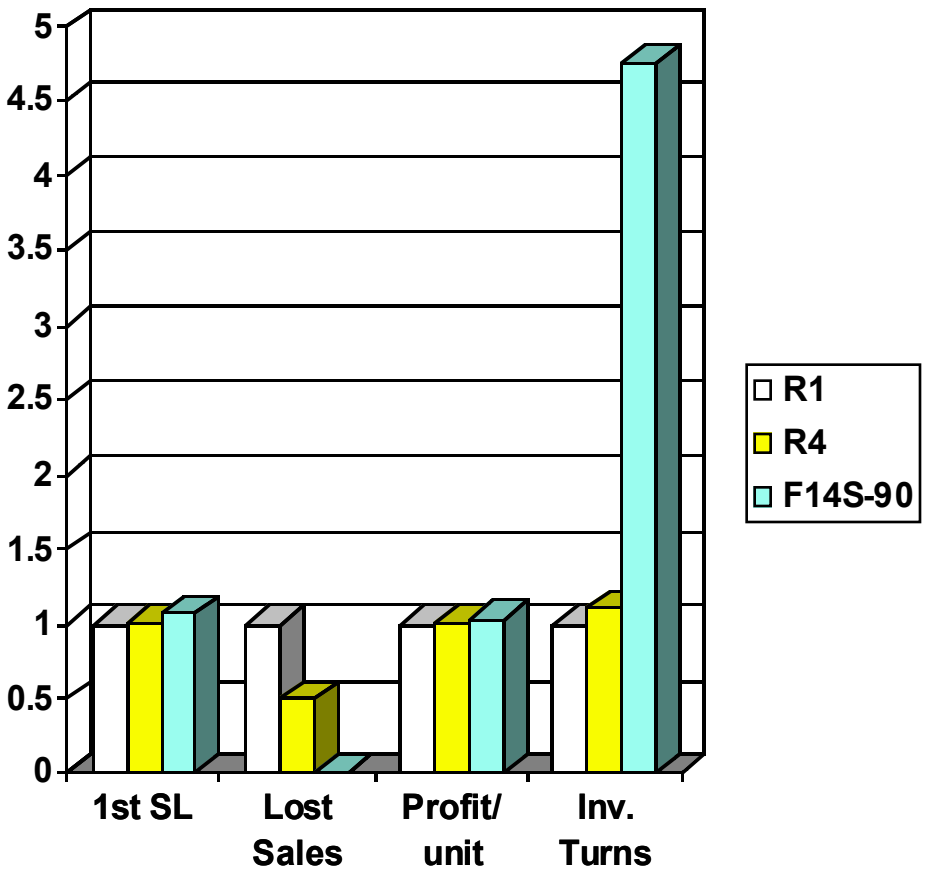


Figure 37. Comparison of Red Base Case (R1) with Shortest Lead Time Scenario (R4) and Best Forecast Error Scenario (F14S-90)

5.2.2.4 Caveats

This analysis is not without flaws, however, the team is aware of most of the shortcomings of this study. A key point of this work is that it is a quick response to the request for analysis for this pipeline. Due to time constraints, not all relevant aspects of the pipeline processes could be represented in the simulation, effectively reducing the influence of constraints in the real system. Further, for the functionality represented, the analysis team was required to make estimates of data instead of using data supplied by the pipeline principal for that company, potentially biasing the results of the study. NJPSim is a deterministic model mainly for the reason that the companies were unable to supply probability distributions describing activity times; it is not an inherent limitation of the simulation. If the form and parameters of the distributions or detailed data are made available, then NJPSim can easily be modified to be a stochastic simulation. Nonetheless, the analysis supports some straightforward conclusions.

5.2.3 Dynamic Analysis Conclusions

In the analysis based on the NJPSim model and simulation, the conclusions are relevant only to the pipeline structure that was studied, and should not be construed as applicable to all pipeline architectures or products. The conclusions of the analysis are:

- reducing forecast error is effective in improving pipeline performance;
- decreasing lead time is generally beneficial, but comparatively less effective;
- reducing forecast error works best with a coordinated replenishment schedule;

improved model fidelity would lead to better resolution of the trade-off between forecast accuracy and lead time.

6. Project Activities and Deliverables

The following table lists activities performed and deliverables produced in the execution of this project.

Table 17. Project Activities and Deliverables

Item #	Activity and Deliverable	Reference
1.	Requirements Document	See Reference List
2.	Supply-chain Architecture, Modeling Techniques, and Methodology	Section 4
3.	Information Package • Business and Information Flow Charts • Activity Flow Chart • Value Analysis • Hierarchy of Controls • Sub-Model Data Sheets	 Appendix H Appendix G Appendix C Appendix D Appendix L
4.	Static Modeling and Analysis	Section 5.1
5.	Dynamic Modeling and Analysis	Section 5.2

7. Conclusions

The purpose of the NJP analysis was to identify ways in which time and cost might be removed from the production of a nylon jacket through application of analytical tools. The analysis has identified a comprehensive supply-chain design architecture and methodology which can be applied to improve pipeline performance. Pipeline analysis has been completed using both static and dynamic methods. The analysis identified the following conclusions relevant to this nylon jacket pipeline:

- wait activities within the supply-chain are due to inventory stocking policies required to meet seasonal demand, lack of supply chain coordination, and inclusion of non-value added processes,
- methods engineering provides opportunities to eliminate work content or improve productivity and efficiency in the supply-chain,
- when replenishment schedules are coordinated with appropriate inventory policies, reducing forecast error is effective in improving integrated supply-chain performance, reduction of lead time is generally beneficial as well, and
- improved dynamic model fidelity would lead to better resolution of the trade-off between forecast accuracy and lead time.

The problem of supply-chain design has been approached as that of a *cooperative* system design. The composition of a cooperative system as the collective behavior of its constituents, offers a unique architectural framework for applying a distributed problem-solving approach. The decomposition process of the supply-chain enterprise leading up to identification of activities of its Members, reveals behavior of Member entities that is useful in designing the supply-chain design problem. A cooperative supply-chain system model is presented incorporating behavioral traits of its Members. These behaviors have attributes that are essential to modeling separation of Members from their collective identity, Group, in a cooperative supply-chain system. The unique feature of a distributed problem-solving approach to represent behavior of a system through its component entities, offers opportunities to model large-scale supply-chain systems using modular constructs.

8. Recommendations

The NJP analysis was conducted to satisfy a rapid response request from DAMA program members. While this effort was successful in meeting the intent of the analysis, further efforts are required to meet the goals of the fiscal year 1997 plan. Central to the plan's mission is to identify means to cost-effectively reduce time in the Integrated Textile Complex pipeline in general, and the nylon jacket pipeline specifically. Analysis techniques which were developed during the NJP analysis are recommended to be applied and further developed in 1997.

The recommendations included here as those, a) specific to the NJP coordination problem, b) applicable to supply-chain problems in general, and c) are specifically required to reduce lead time in the ITC pipeline.

NJP problem-specific recommendations:

Recommendations in this area emphasize synchronization between various components in the NJP enterprise. Efforts should be undertaken by supply chain members to:

- design forecasting models that facilitate implementation of specific inventory management policies at the member and group levels in the supply-chain,
- incorporate effective signaling mechanisms to modulate bias throughout the supply-chain, and
- develop and enforce forecasting and inventory control standards for the supply-chain.

General Supply-Chain recommendations:

Recommendations in this area emphasize building supply-chain infrastructure to improve coordination and integration in the supply-chain enterprise. These are:

- expand on coordination issues in the supply-chain by building on lessons learned from the NJP analysis, and
- focus primarily on integration problems in the supply-chain.

Efforts required to support ITC lead time reductions

The challenge is to build upon the success of the NJP analysis through more detailed pipeline analysis scenarios. A number of pipeline analyses are proposed for 1997. These analysis scenarios should demonstrate:

- the validation of the supply-chain architecture, modeling, and analysis methodology proposed in this study,
- potential improvements from manufacturing and information technologies, including product postponement techniques and representative logistics studies.

To complete the analysis scenarios, it is proposed that a more robust simulation tool is needed to "drill down" to lower levels of the pipeline. In addition, industry resources must be acquired to support future supply-chain analysis needs.

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Glossary of Terms

AMTEX -- American TEXtile partnership.

Analysis -- The study of a system in relation to a specific problem.

Architecture -- A method of designing and constructing a system.

Backward Propagation -- Expansion of a firm's production and distribution chain backward towards the sources of supply.

Benchmarking -- The practice of establishing internal standards of performance by looking to how world-class companies operate their business.

Bottleneck operation -- A production operation with the least manufacturing capacity for a product.

Carrying Cost -- Total cost of holding a material in inventory, expressed in dollars per unit per period.

Commitment -- Pledges on actions and beliefs entered into between autonomous entities.

Compromise -- Backing down from a publicized position in order to realize common goals.

Control Limit -- A technique that continuously monitors an operation to determine if its outputs meet quality standards. Through this monitoring it is easy to pinpoint processes that are out of control.

Conventions -- General policies and guidelines for honoring commitments made between autonomous entities.

Cooperative System -- A special class of a system where each member works towards accommodating each other's goals, priorities, and objectives.

Coordination -- The process by which an entity reasons about its actions and the anticipated actions of others to try and ensure that the group acts in a coherent manner.

Critical Path -- A path in the project network connecting the starting event (node) and the ending event, such that it passes through critical activities, is called a Critical Path. A critical path is the longest path through the network.

DAMA -- Demand Activated Manufacturing Architecture. DAMA is one of eight projects in the AMTEX program.

Decision-Making – Actions to commit resources and processes. These actions are hierarchical and interdependent, that is, strategic, tactical, and operational decisions are hierarchical decisions, performed interdependently.

Decomposition -- The process of logically breaking down a complex system (whole) into simple manageable (problem-solving) pieces (parts).

Demand Behavior, **cycle** -- An up-and-down repetitive movement in demand.

Demand Behavior, **random variations** -- Movements in demand that do not follow a trend.

Demand Behavior, **seasonal pattern** -- An up-and-down repetitive movement in demand trend that occurs periodically.

Demand Behavior, **trend** -- A gradual, long-term up or down movement of demand.

Domain -- The field of inquiry.

Enterprise -- A collection of entities (systems) assembled towards achieving common goal(s).

Explosion -- A systematic breakdown of a system entity into it's lower level components.

Exponential Smoothing Method -- A short-range forecast method that takes the forecast for the previous period and adds an adjustment to obtain the forecast for the next period.

Forecast Error -- Difference between actual and forecasted demand.

Goal -- A quantifiable measure of performance for a system entity at the highest level of interaction, for a specific model..

Group -- A system entity that assumes the behavior of its members. It may or may not be a physical entity, but it captures the essence of a joint relationship between various members.

Group Dynamics -- A collective behavior acquired by the group as it negotiates both implicit and explicit behavior of its members.

ITC -- Integrated Textile Complex – includes the sectors of fiber through retail.

Integration -- A concept to unify components of a system.

Lead Time -- Length of time required to replenish the inventory for a material from the time that a need for additional material is felt until the new order for material is received in the inventory and is ready to use.

Life-Cycle -- A phased depiction of a system from its conception to decline.

Logistics -- The movement of materials, parts, and finished goods from suppliers, between distribution sites, and to customers.

Mean Absolute Deviation (MAD) -- A measure of forecast model accuracy.

$$\text{MAD} = \frac{\text{sum of absolute values of forecast errors over a number of periods}}{\text{Number of Periods}}$$

Member -- System entities that are partners in a supply-chain arrangement.

Methods / Techniques -- Approaches to performing different tasks. Methods / techniques are based on sound theories.

Methods Engineering -- A systems based approach that deals with design, analysis, and implementation of productivity to integrate concepts of cost, time, and standards associated with activities in the enterprise.

Model -- A representation of a system.

Moving Average method -- A short-range forecast method that averages data from a few recent past periods to predict the forecast for the next period.

Negotiation -- Process of improving agreement on common viewpoints through structured exchange of pertinent information.

Objective -- A quantifiable measure of performance for a system entity at the lowest level of interaction, for a specific model.

Opportunity Cost -- Cost in the form of profits foregone.

Optimization -- is a technique to obtain the best answer among possible alternatives.

Order Point -- The point (quantity or time) when an order is placed for a material.

Order (Replenishment**) Quantity** -- Quantity of a material ordered each time inventory is replenished.

PERT (Program Evaluation and Review Technique) -- An aid to efficient project management. It is a tool to plan, schedule, and control a large number of activities in a project within the specified technological sequence. Another prominent method for project management is **CPM** (Critical Path Method).

Pareto-Optimality -- A condition that describes that a solution to a problem may not necessarily be optimal. This is specially applicable in a multi-criteria multi-decision environment, such as a supply chain where members may have competing goals.

Policy -- A course of action(s) identified to achieve stated goal(s) for an entity.

Process -- A series of actions performed to convert an input to an output.

Process Modeling -- Representation of various processes and their relationships in a system towards achieving its objectives.

Produce-to-order -- A production philosophy that advocates producing products only after orders are in hand.

Produce-to-stock -- A production philosophy that advocates producing products ahead of time and stocking them in inventory until a demand is generated.

S.K.U. -- A stock keeping unit. A part, material type, or a product for which stock (inventory) is planned.

Safety (or Buffer) Stock -- Stock of finished products that can be used when demand is greater than anticipated or when supply is less than expected.

Service Level -- the probability that the amount of inventory on hand during the lead-time period is sufficient to meet expected demand.

Standard Error (or the Standard Deviation) σ -- Used as a measure of forecast error, especially in computing statistical control limits.

Standard Time -- The time estimated to be required for an average worker to perform an activity under normal circumstances and conditions.

Standards -- Accepted norms of performing normal tasks.

Stockout -- Reduction of a material's usable inventory level to zero.

Supply Chain -- A network of autonomous business entities formed to solve a common business problem. The term *pipeline* used in this report also connotes a supply-chain.

Synchronization -- is the art of ensuring that the components of a complex system, such as, a supply-chain are aligned towards achieving its common goal(s).

System -- An assembly or a combination of elements of *parts* forming a complex *whole*.

Tracking Signal -- A measurement showing whether a forecast has had any built-in biases over a period of time.

Value Chain Analysis -- The **value chain** is a model of business activities and how they add value to a business. By analyzing the value chain, an analyst gains insight into how an organization works. It helps the analyst to appreciate those activities that, if performed, optimally, can return the most value to the business as a whole.

Value Engineering -- This is a Systems based approach that deals with design, analysis, and implementation of productivity concepts aimed at bringing value to the enterprise in all aspects of its operations.

W.I.P. (Work in Process) -- Inventory of partially completed products that are between processing steps.

Work Design -- deals with improvement of existing work activities and the design of new work