# A NEW FRAMEWORK FOR SUPPLY CHAIN MANAGEMENT: REVIEW, CONCEPTS AND EXAMPLES

**Eleftherios T. Iakovou**

*Associate Professor, Department of Industrial Engineering*
*Director, Perry Ellis International Logistics Research Institute*
*University of Miami, Coral Gables, FL, USA*
*Phone: +(305) 284-2391, eiakovou@miami.edu*

***Abstract***

*Manufacturing and distribution systems have experienced radical changes during the last ten years within a very competitive environment with continuously shorter life cycles and amazingly increasing number and variety of products ranging from apparel and toys to computers. The decision-making models used most often by industry and preached by academia have been proven inadequate to most of the retailing and manufacturing environments that we studied.*

*In this paper, we first summarize the unique challenges of supply chain management for manufacturers and retailers, present current realities and then review past efforts. We demonstrate why the classical inventory and distribution management paradigms used in the past are inadequate for addressing the new realities, by examining their basic assumptions. We further document the strategic role of variability in such environments and present briefly a case study from the mapping of the supply chain of a U.S.-based international apparel designer and marketer. Subsequently, we present best practices and discuss the enhanced role of information flow and information technology. Finally, we outline the need for a new supply chain framework by identifying the unique challenges and opportunities that exist for both academia and industry.*

**Keywords**: supply chain management, inventory management, lean retailing, apparel manufacturing

## A. Introduction

Managing a supply chain supply involves inventory management, material handling, warehousing, distribution and transportation while interfacing closely with manufacturing and marketing. Logistics supply chains arise in a plethora of governmental and corporate environments including among others, manufacturing and retail firms, food producers and distributors, transportation carriers, the military and service companies.

The role of supply chain management has changed dramatically from a back office support function to a strategically important core issue and a source of competitive advantage within the global, electronic economy. This change is due to the following:

- *High costs of operating supply chains*. Logistics costs for the U.S. private sector in 1993 accounted for 670 billion dollars (roughly 11% of the U.S. GDP). As it has become clear in recent years that many companies have reduced unit manufacturing costs as much as practically possible, many of these companies are discovering the magnitude of savings that they can achieve by planning and managing their supply chains more effectively (a striking example, is the success of Wal-Mart's cross-docking logistics strategy).
- *Deregulation*. Rail, trucking and air transportation in the U.S. have been shifting from highly regulated to increasingly open market industries, thus adding to the complexity of logistics choices and costs.
- *The emergence of global markets*. As the marketplace becomes increasingly global moving goods from origin to destination on a global scale is logistically challenging involving a large number of complex links, varying costs (unit manufacturing costs, taxes, currency fluctuations) and intermodal transportation. Further, communications infrastructure in some countries, is not sophisticated enough to support the reliable flow of information throughout the supply chain.
- *Customer service*. In the new demanding market environments supply chains must deliver products promptly, consistently, and accurately while adjusting quickly in changing market patterns (especially, since in these markets the life cycles of products are constantly reduced and just in time, flexible production is essential for corporate success). Customers really demand to have the right product, at the right quality, at the right price, first time, on time, at the right place; else, thay have the option to go somewhere else.
- *Technology*. Dramatic recent advances in technology have affected significantly logistics operations (e.g., automated bar code tracking of equipment, computerized decision support systems). Furthermore, the proliferation of e-commerce impacts severely retail and business-to-business supply chains worldwide. Electronic commerce must be supported by a reliable and effective product delivery system in order to maintain its appeal and continue its phenomenal growth. Creating new distribution environments catering to the needs of e-tailers is critical and challenging while it is not a case of one-size-fits-all.

Within this environment, the necessity of managing inventories efficiently is critical. However, despite the dramatic changes that have occurred in manufacturing, warehousing and distribution the basic approaches practiced by industry and taught in academia today appear to have serious flaws. The classical paradigm of academic research and corresponding teaching has been misguided.

In this paper, we begin by summarizing the unique challenges of supply chain management first for manufacturers and then specifically for retailers, present current realities and review past efforts; we draw parallelisms between manufacturing and retailing throughout the manuscript. We then demonstrate why the classical inventory and distribution management paradigms used in the past are inadequate for addressing the new realities, by examining their basic assumptions. We further document the strategic role of variability in such environments, we present best practices and discuss the enhanced role of information flow and information technology. We also present briefly some of the core issues that we have been facing during our involvement with an international U.S. based apparel designer and marketer. Finally, we outline the need for a new supply chain framework by identifying the unique challenges and opportunities that exist for both academia and industry, while further discussing future trends.

**B. Inventory and Supply Chain Management: Background**

The first mathematically based methods for controlling inventories developed at the beginning of the century focused on the tradeoff between fixed order cost and inventory carrying costs. These efforts led to the development of the well-known economic order quantity (EOQ) model that remains quite prevalent in industry today as the basis for many production planning and inventory control decision support systems. The next wave of research efforts began in the 1950s and modeled stochasticity in the demand process. Fundamental contributions on this arena include: (i) proof of optimality of (s,S) policies (Dvoretzky et al., 1953), (ii) formulation of the basic properties of multi-echelon systems (Bessler and Veinottt, 1966, Clark and Scarf 1960), (iii) development of multiple items models with resource constraints (Hadley and Whitin, 1963) and (iv) development and implementation of multi-item, multi-echelon models (Muckstadt 1973, Cohen et al., 1986, 1988, 1989, and specifically for repairable items Sherbrook, 1968).

In addition, the manufacturing industry adopted materials requirements planning (MRP) as an integrated framework for purchasing, production and inventory control. Advances in information technology further facilitated the implementation of such models. U.S. manufacturing firms have shown a rapidly growing interest in commercial enterprise resource planning (ERP) products (such as e.g., SAP and Oracle) that are IT-based synchronized MRP "push" systems. This trend started in the early 1990s as companies looked to coordinate and standardize data transactions pertaining to planning, inventory, information and cash flow. However, in spite the surge of ERP products the reports on their performance are mixed so far. Leading supply chain software vendors like i2 Technologies, Manguistics, Chesapeake (acquired recently by Aspen Technologies), and Red Pepper (acquired by PeopleSoft) have made available products that integrate optimization modeling, heuristics (often very simplistic ones), computer and networking hardware, and database design. Specifecally, in the manufacturing sector, since the late 1970s, there has been a focus in implementing just-in-time manufacturing concepts for improving efficiency. KANBAN systems (and their more sophisticated hybrids) are information management systems that can be used for inventory replenishment and their usage has generally led to improved responsiveness, reduced cycle times, and reduced waste.

While such improvements have resulted in better management of inventories, still the science of inventory management remains incapable of addressing satisfactorily many practical real world environments. Too much inventory exists wasting billions of dollars in investments and holding costs annually. Demand goes often unsatisfied for long periods of time for critical components because of the unavailability of the proper amount of inventory.

Many dramatic changes have occurred in the last decade that exacerbated the need of even more sophisticated and responsive to the needs of the industry inventory management. As customers started demanding better quality and service, manufacturers began recognizing that their manufacturing and distribution policies were inefficient, exhibiting long cycle times, large lot sizes, low yield, lengthy and very unpredictable lead times. Further, the length of time between placing an order and its due date has been decreasing dramatically. Customers often expect same day service and even when they are willing or they have to wait they expect to be quoted with accurate delivery lead times. In addition, the variety of products and part numbers that are requested has increased while at the same time the life cycle of the products has shortened. These last two trends have placed enormous pressure on supply chains; companies that cannot meet these challenges will face tremendous difficulties within the confines of the new economy. Indicatively, Singhal and Hendricks (*ORMS Today*, 2001, pp. 21-24) after searching for articles in the *Wall Street Journal* and Dow Jones News Service from 1989 to 1998 for news of supply chain problems, report that when a company announces supply chain malfunctions (such as part shortages, changes requested by customers, new product ramp/rollouts, production, development and quality problems) its stock priced tumbles nearly 9 percent and losses can be as great as 20 percent over six months (leading to an average reduction of shareholder wealth by $120 million or more per company).

Such market demand trends have changed forever the way that retailers and their manufacturers/suppliers manage their supply chains. Using standard performance measures such as inventory turns, it is evident that the way retailers manage their inventories lags behind other sectors, such as manufacturing. However, it is also true that retailers have to face unique challenges and complexities. For example, retailers have to maintain stock at many geographically dispersed areas and further they need to manage a very large number (often in the order of several hundred thousand) of SKUs (stock keeping units). Until recently, demand rates at the store level were reported only in aggregate form with significant delays and inaccuracies.

Abernathy et al. (2000) describe how information technologies have changed the nature of retailing and more specifically, the operation of a core US manufacturing industry, apparel. Advances in information technology allow now retailers to exchange point-of-sales (POS) data with their suppliers and accordingly require manufacturers to replenish orders much faster than traditionally. Apparel manufacturers cannot afford to fill retail orders in months and hence, they cannot afford to make decisions solely based on cheap labor. Instead, manufacturers have to reshape their production planning methods, their inventory practices and sourcing policies. The set of these new practices comprises the sector's response to the new market challenges by adopting some of the fundamental approaches undertaken by the rest of the manufacturing field and is known as *lean retailing* (Abernathy et al., 1999).

The introduction of the *Quick Response* initiative in 1995 by the Crafted with Pride in the U.S.A. Council epitomizes the efforts of the U.S. textile and apparel manufacturers to increase their competitiveness, under the paradigm of lean retailing (Hammond, 1992). In a nutshell, *Quick Response* is a strategy for tying apparel and textile retailing operations to apparel and textile manufacturing operations, in order to provide the flexibility needed to respond quickly to shifting demand patterns. The strategy is comprised of a combination of business practices and technology so that domestic manufacturers provide more suitable products, higher customer service levels, and shorter lead times than those offered by lower-priced foreign competitors. *Quick Response* aims to reduce inventory levels, increase inventory turns, and avoid forced markdowns and stockouts. Implementation of a *Quick Response* program requires numerous organizational and technological changes in the ways that textile, apparel, and retail firms do business. A *Quick Response* strategy involves three steps: (i) consumer testing to narrow product selections to the right products for the right markets; (ii) implementing an effective information pipeline; and (iii) instituting short-cycle replenishment. Under this paradigm a number of technologies are necessary to support the required improved logistics operations including ordering, manufacturing and distributing of apparel products. Such technologies include among others: electronic data interchange (EDI) and data processing, shipping container marking (SCM), bar coding, computer-aided design (CAD), flexible manufacturing technologies, such as unit production systems (UPS) and standards across firms.

*Lean retailing* and *Quick Response* have placed increased demands on apparel manufacturers. Manufacturers have to now be able to: (i) track and respond to product orders in real time at a SKU level (style, color, fabric, size), (ii) exchange information electronically with a retailer about outstanding orders (e.g. providing advanced shipment notices, ASNs), and (iii) ship containers to retailers properly marked with bar codes denoting contents. We have seen as a common practice within the industry extremely strict requirements from the part of retailers concerning the proper packing, contents, and barcoding of cartons and containers. For example, many times manufacturers have to place apparel items on hungers prior to shipping them to the retailer's distribution center so they can be used immediately for display. To our surprise we found out that very often apparel manufacturers have to pay heavy "cashbacks" to retailers due to quite trivial flaws concerning the packing of shipped containers. This practice has become so much widespread that these penalties have become a major source of revenue for retailers. Not surprisingly though, we found out that mass merchants like Wal-Mart, national chains like J. C. Penney and department stores like Federated have much greater leverage on their apparel manufacturers (also reflected on their contractual agreements with their suppliers).

## C. Variability is of Strategic Importance

Given all these improvements in both manufacturing and retailing why is it that we cannot provide consistently 100% on time delivery? There are many reasons why the service levels are poor but a prime reason has to do with the fact that variability of the demand over the reduced lead times is often too great and at the same time it cannot be estimated easily. Even more so the demand variability increases as one moves upstream in the supply chain leading to the *bullwhip effect*. Chen et al. (1999) present a synthesis of the factors that can cause bullwhip. We provide below a list of the major sources of variability and further comment on each of them based on our experience with both manufacturing and retailing:

(a) The first such factor is *demand forecasting*; at the end of each period, the retailer observes the more recent demand, updates accordingly his/her demand forecast and then uses the updated forecast to update the target inventory level (assuming that a simple order-up-to inventory policy is followed). Exactly this practice of updating the forecast and the order-up-to point in each period results in increased variability in the orders placed by the retailer.

(b) *Lead times* can magnify the increase in variability due to demand forecasting. For example, a formula that is commonly employed to calculate the order-up-to level for any period is: order-up-to level **=** expected lead time demand **+** safety stock factor **x** standard deviation of the lead time demand. Any changes in our estimates of the parameters (first two moments) of the demand process will be magnified by the lead time. Furthermore, the safety stock quantity in the above formula depends on knowing the upper tail of the probability distribution of the lead time demand and its standard deviation. Academicians often assume the demand to be normally, exponentially, Poisson or negative binomially distributed, leading to the development of analytically tractable models. However, estimating the distribution parameter values is often quite challenging in today's manufacturing and distribution environments. Further, the classical assumptions of stationary and independent demand from day to day and part-to-part is quite myopic for many real world environments.

(c) *Batch ordering* further contributes to the manufacturer seeing a distorted and highly variable pattern of orders; if the retailer uses batch ordering, then the manufacturer observes a quite large order followed by periods of no orders. As the value of components and parts continues to drop and the cost of capital remains low, batch sizes will continue to be large throughout various stages of the supply chain.

(d) *Supply shortages* can further lead to inflated orders from the retailer to the manufacturer (in anticipation of an item going in short supply).

(e) *Price variations* like promotions and clearance sales can cause distorted demand patterns and increased variability in demand. The every day low pricing strategy practiced by leading retailers (such as Procter and Gamble) is an attempt to lower this variation by smoothing customer demand and eliminating price incentives.

Another cause of variability is due to the fact that in a very competitive environment products are often in and out of favor quickly, leading to dramatic swings in demand. Such variable demand patterns force the production system to respond either by producing to meet the high requirement promptly or by satisfying demand from inventories of either finished goods or partially completed subassemblies. Further, manufacturers tend to utilize a number of distribution centers (DCs) so that they can respond faster to orders placed by regional customers. However, this policy too burdens the system with more variability since the demand experienced at each warehouse has higher variability than the one experienced by the overall system. Forecasting consequently, becomes much less accurate as the number of DCs increases leading to increased inventories and reduced service levels.

Given all these sources of variability, how do the production and inventories paradigms used throughout the industry perform? MRP systems require as input a large amount of data including, bill of materials (BOM), historical demand, lead times, target safety stocks, current orders, backlogged demands, and work in process (WIP). Given these data MRP establishes desired production and inventory levels. First, a master production schedule (MPS) for finished goods is generated and then thorough a BOM explosion and using the provided lead times production requirements are computed for raw materials, components, and subassemblies. However, these plans are produced under the assumption of infinite capacity. Further, lead times are rarely known in advance, deterministic, and independent from part to part. Actually, the lead times act as surrogates for capacity and are a function of the product mix (types and quantities) that is currently being produced, the availability of the required equipment, tooling, and personnel.

Both MRP and distribution requirements planning falsely presume that safety stocks and inventories can be planned and balanced among all locations within the distribution network, thus ignoring the dynamic nature of the system that is due to randomness stemming from lot sizing rules, lead times, forecasting techniques and other managerial policies. More specifically, safety stocks are usually calculated using single item single locations models leading to policies like (Q,r), (s,S), or an order-up-to R policy. Even though there exist models that account for stochastic lead times they are seldom used in practice; even these models though, do not capture the complexities of today's supply chains as described earlier. As it is well known from classical queuing theory models, capacity utilization, customer service levels and inventory requirements are interdependent and cannot and should not be treated in isolation from each other. Consequently, it is impossible for any real world dynamic capacity constrained environment to manage inventories using the standard MRP type models that we presented above; items cannot be managed independently, since they compete demanding capacity and often common components, they have different demand patterns with different predictability, and different lead time requirements.

**D. Lessons from Industry, Challenges and Future Trends**

We have been working extensively with a leading designer and marketer of a broad line of sportswear, including sport and dress shirts, sweaters, urban wear, and casual and dress pants and shorts to all levels of retail distribution. The company's distribution channels include regional, national and international department stores, chain stores, mass merchandisers and specialty stores throughout the United Sates, Puerto Rico and Canada. The company currently uses independent contract foreign manufacturers to produce all of their products. It has more than 100 suppliers from countries in the Far East and other parts of Asia, Mexico and from countries in Central America. The company operates a distribution center in Miami, Florida with an aggregate square footage of approximately 200,000 square feet and the task of handling approximately 40,000 SKUs.

The DC is a focal point of the supply chain for the implementation of *lean retailing*. It is supposed to be quite different than the classical warehouse which keeps inventories ordered ahead of sale; instead, a DC routes incoming shipments to retailer stores or to a retailer's distribution center. Incoming shipments usually arrive as full truckload or less than truckload deliveries from vendors. Within the DC apparel items are: (i) "*picked and packed*", i.e., packages are opened and then items are selected to be repacked and then shipped, or (ii) "*cross-docked*". In the latter case, goods are unloaded at one bay of the DC and then are moved by conveyor to another area of the DC for shipment usually the same day. Picking and packing is a very intensive manual operation and it requires the items to reside longer within the DC. On the other side, cross-docking needs more advance preparation and it begins when apparel items are unloaded from trucks; items are coming either in cartons or pallets. These packages are then scanned via the bar code on the shipping container marker (SCM); the bar code contains information about the exact contents of the package. Shipments, after a purchase order verification (again the DC's database) are sent to docks where orders can be consolidated for direct shipment to retailers.

At the core of managing a DC that operates within a *lean retailing* environment is the warehouse management system (WMS). WMS is responsible for handling the enormous data processing needs associated with the thousand transactions occurring daily for incoming and outgoing systems by updating, reconciling and disseminating information. A WMS system can have a positive impact only if interfaces seamlessly with the corporate ERP systems and at the same time have the ability to interact with apparel manufacturers concerning incoming orders and retailers concerning outgoing shipments via EDI. It is our experience that when management employs WMS in isolation of the other components then results are quite inefficient. The vast majority of the WMS systems that we have encountered, contrary to efforts of the vendors in proving the opposite, lack any intelligence (they are simply glorified databases). In addition, these systems have no understanding of how they affect inventory replenishment policies and in general how they fit within the entire supply chain puzzle. Further, management often lacks any knowledge of the shortcomings of the WMS in place and still depends on its interaction with the ERP system, which as we outlined earlier most of the times cannot capture effectively system variability.

Indicative of the key role of variability is our finding, after studying the weekly demand variability of the most profitable items (classified as type "A" items following a Pareto ABC analysis), that SKUs of exactly the same shirt type that differ only in size exhibit dramatically different coefficient of variation (CV). As a matter of fact our experience simply verified the well-known fact that high volume items have lower CVs (in the range of 0.3 to 0.7) than low volume items due to the demand pooling effect (Abernathy et al., 2001, Iakovou, 2001). Prior to our involvement all SKUs of the same line were treated the same way as far as inventory policies are concerned, even though this led to severely suboptimal policies. An optimal policy would be for the apparel manufacturer to determine unique inventory replenishment policies for each SKU. The implementation of such SKU level analysis can holistically optimize profit, inventory holding costs and retailer service (order fulfillment) rates (Abernathy et al., 2000, Iakovou, 2001). Further, variability is of strategic importance and we utilized for example such an analysis in evaluating the proper sourcing strategy for company along with the optimal policy for expanding its DC capacity (should the current Miami based DC be expanded or another one be built in Latin America?). An intelligent policy would move low volume, high CV

SKUs close to markets, while high volume, predictable SKUs can be moved further offshore if the labor cost makes that more cost effective.

As supply chain management transcends a plethora of classical academic disciplines, it is of no surprise that academia has been slow to react to the radical changes of the market in general, and of the supply chains in particular. Often, industry has surpassed academia in tackling efficiently the right issues in supply chain management; however, other times vendors have done a disservice to the community by not acknowledging and by not educating corporate users about the limitations of their developed products.

One of the most important changes in retail inventory management has been the introduction of vendor managed inventory (VMI) programs. With VMI a manufacturer assumes responsibility for setting desired inventory stocking levels for the manufacturer's product in the retail store. Following the determination of the inventory levels, POS and real time on hand inventory data are transmitted through EDI to the manufacturer who then decides how much (and often when to ship) so that system-wide manufacturing and transportation costs are minimized while inventory service requirements are still satisfied. The benefits of such policies where that interested parties are working synergistically and not competitively, are well documented. For example, in the grocery industry (where these programs are also known as continuous replenishment programs, CRP, or continuous product replenishment, CPR) implementation of VMI programs has been shown to increase inventory turns anywhere from 50 to 100 percent (Clark and Hammond, 1997). There are however, many challenges in implementing successfully VMI programs. Specifically in the apparel industry for example, we have seen that most retailers are unwilling to give up control of the merchandise on the shelf to their manufacturers (especially, given their high leverage on their relationships with their suppliers). Often, this is due to the lack of supply chain management sophistication of many manufacturers. Indeed, in the apparel industry, it appears that game theory is a more appropriate methodological tool to apply since retailers and suppliers operate supply chains independently.

Finally, the Internet is proving to be a catalyst in providing supply chain management solutions (as Dell's success has so vividly shown), while it further provides opportunities for optimization based decision support systems due to: the emergence of new business models (e.g., Webvan's), businesses become more aware of the value of such models, and more willing to implement them (since the usage of the Internet might ease some their IT related implementation concerns) and the proliferation of business-to-business (B2B) relationships. These solutions will be further used for executing orders faster, disseminate information promptly to suppliers and customers for planning (thus eliminating some of the bullwhip sources) and lastly improve design and customer relationship management (CRM).

**References:**


1. Abernathy, F. H., Dunlop, J. T., Hammond, J.H., and D. Weil, *A Stitch in Time: Lean Retailing and the Transformation of Manufacturing*, Oxford University Press, New York, 1999.
2. Abernathy, F. H., Dunlop, J. T., Hammond, J.H., and D. Weil, "Control Your Inventory in a World of Lean Retailing", *Harvard Business Review*, pp. 169-176, November-December 2000.
3. Bessler, S., and A. Veinott, "Optimal Policy for A Dynamic Multi-Echelon Inventory Model", *Naval Research Logistics Quarterly*, Vol. 13, pp. 355-389, 1966.
4. Chen, F., Drezner, Z., Ryan, J., K., and D. Simchi-Levi, "The Bullwhip Effect: Managerial Insights on the Impact of forecasting and Information on Variability in a Supply Chain", in *Quantitative Models for Supply Chain Management*, Tayur, S., Ganeshan R., and M. Magazine (Eds.), pp. 419-439, Kluwer's International Series, 1999.
5. Clark, T., and J., H., Hammond, "Reengineering Channel Reordering Process to Improve Total Supply Chain Performance", *Journal of Production and Operations Management*, 6, No. 3, pp.248-265, Fall 1997.
6. Clark, A., and H. Scarf, "Optimal Policies for a Multi-Echelon Inventory Problem", *Management Science*, Vol. 6, pp. 475-490, 1960.
7. Cohen, M., P. Kleindorfer, and H. Lee, "Optimal Stocking Policies for Low Usage Items in Multi-Echelon Systems", *Naval Research Quarterly*, Vol., 33, pp. 17-38, 1986.
8. Cohen, M., P. Kleindorfer, and H. Lee, "Service Constrained (s,S) Inventory Systems with Priority Demand Classes and Lost Sales", *Management Science*, Vol. 34, No. 4, pp. 482-499, 1988.
9. Cohen, M., P. Kleindorfer, and H. Lee, "Near-Optimal Service Constrained Stocking Policies for Spare Parts", *Operations Research*, Vol. 37, No. 1, pp. 104-117, 1989.
10. Dvoretzky, A., J. Kiefer, and J. Wolfowitz, "On the Optimal Character of the (s,S) Policy in Inventory Theory", *Econometrica*, Vol. XXI, pp. 586-596, 1953.
11. Hadley, G., and T. Whitin, *Analysis of Inventory Systems*, Englewood Cliffs, NJ, Prentice Hall, 1963.
12. Hammond, J., "Quick Response in the Apparel Industry", *Harvard Business School Note* No. 690-038, 1992.
13. Iakovou, T., E., "Reengineering of a Distribution Center within a Lean Retailing Supply Chain Environment", Department of Industrial Engineering, University of Miami, working paper, 2001.
14. Lee, H., "Effective Management of Inventory and Service through Product and Process Redesign", *Operations Research*, Vol. 44, pp. 151-159, 1993.
15. Muckstadt, J., "A Model for Multi-Item, Multi-Echelon, Multi-Inventory Systems", *Management Science*, Vol. 20, No. 4, pp. 472-481, 1973.
16. *ORMS Today*, Vol. 28, No. 1, February 2001.
17. Sherbrooke, C., "METRIC: A Multi-Echelon Technique for Recoverable Item Control", *Operations Research*, Vol. 16, pp. 122-141, 1968.