Supply Chain Inventory Replenishment: A Benefit Analysis Model

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This paper details an action research project conducted to (a) improve supply chain management processes for a mid-market manufacturer of electronic components while (b) extending research on decision processes in small- and medium-sized enterprises (SME's). The manufacturer faced long and unpredictable lead times on critical materials sourced from an affiliated overseas supplier. The company had responded by keeping excessive safety stock, but lacked a mechanism for quantifying the economic impact of this policy. We present a multiple-scenario model that calculates the economic impact of reduced inventory levels and carrying costs. We also present qualitative analysis from the study, yielding research questions involving (1) a *cost not to solve* approach to change management proposals, (2) decision processes in *nested SME's* that are part of a large holding company, and (3) the potential use of *cellular supply chain management* techniques to optimize processes within a large holding company.

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I. INTRODUCTION

This paper is drawn from an action research project focused on a mid-market manufacturer of electronic components. The dual objectives of the action research project were (1) operational process improvement for the manufacturing company, and (2) qualitative analysis of change management phenomena in small to medium-sized enterprises (SME's). Contributions from this research include (a) the development of a quantitative model based on the economic order quantity algorithm (EOQ) to optimize replenishment planning, (b) insights regarding the use of EOQ-based techniques to support inventory management decisions in SME's, and (c) propositions regarding decision process characteristics and constraints affecting SME's that can be evaluated in future research.

The paper presents a quantitative model that was developed in response to a need identified in an early phase of the action research project. The company was faced with long and unpredictable lead times on critical materials sourced from an overseas supplier, which happened to be an affiliated company. The company had traditionally responded to this uncertainty by keeping excessive safety stock on hand for these materials, but lacked a mechanism for calculating optimal safety stock levels or quantifying the economic impact of the excessive safety stock. The model presented in this paper uses thirteen input variables to calculate the potential economic advantages of alternative scenarios in terms of reduced inventory levels and inventory carrying costs.

This research exemplifies the use of multiple methodologies in operations management, which has frequently been advocated by operations management scholars (e.g., Craighead and Meredith 2008, Carter et al. 2008). While the use of case studies to identify a problem and develop a quantitative model in response to the problem is not unusual (Grofsler et al. 2008, Tang and Teunter 2006, Oliva and Sterman 2001), the development of quantitative models in the context of an action research study in operations management is rare. The model presented in this paper can be adapted to any supply chain situation involving alternative scenarios for the duration and variability of replenishment lead times.

The remainder of the paper is organized as follows. The second section presents a literature survey, with emphasis on the application of operations management techniques to SME's. The third section provides an overview of the action research project and discusses the use of the action research methodology as it was applied in this study. The fourth section describes the operational environment at the subject manufacturing company, and defines the lead time duration/variability problem. The fifth section details the methodology, assumptions, and calculations used in the benefit analysis model. The sixth section presents the results of the benefit analysis model using indicative data for one base case and twelve alternative scenarios. The seventh section presents and discusses the results, significance, qualitative findings, limitations, and possible extensions of this research. The eighth section presents a summary and concluding comments.

II. LITERATURE SURVEY

Literature that underpins this research is reviewed in four parts: an overview of the action research methodology; the challenges specifically associated with operations management in SME's; supply chain integration and related performance effects; and the use of EOQ-based models to support inventory management decisions.

2.1. Action Research

The use of research methods involving direct contact with the phenomena being investigated is widely recognized as useful in operations management (Craighead and Meredith 2008, Meredith 1998). Papers advocating and defining such methods appear in the operations management literature with regard to case and field studies (Meredith 1998), plant-based research (Hill et al. 1999), and action research (Coughlan and Coughlan 2002).

The use of qualitative methods such as case studies and interviews in conjunction with quantitative models is an accepted practice in operations management research (Grofsler et al. 2008). As an example, Oliva and Sterman (2001) combined a case study investigation with a simulation model to examine the impact of total quality management.

Action research is considered to be a subset of case study research (Coughlan and Brady 1995). Action research requires the researcher to become an active participant in the subject under study, and to exert a positive influence on the situation while collecting data and observing dependent variables (Meredith et al. 1989) rather than working as a neutral observer. In comparison to operations management, action research is more common in medicine and psychology, where researchers often analyze and present the results of corrective and rehabilitative actions they have prescribed (Coughlan and Coughlan 2002).

Action research is an iterative methodology, with information collection leading from theory development to implementation, and implementation providing new information for further theory development (Coughlan and Coughlan 2002). For that reason, it is possible for multiple research papers to be drawn from a single action research project (Coughlan and Brady 1995).

Action research can be conducted in the context of a consulting project, and has been advocated for use in operations management in that it provides a deeper understanding of the system under study than a strictly data-centric analysis (Coughlan and Coughlan 2002; Naslund 2002). Action research does not require a full factorial experimental design, but is valued because it provides results of immediate relevance to the organization under study (Meredith et al. 1989). The action research methodology was defined by Lewin (1946) and was initially presented as an appropriate research approach for the organizational sciences by Susman and Evered (1978). A useful list of the ten major characteristics of the action research methodology is provided by Gummesson (2000).

2.2. Operations Management Challenges in SME's

The special management challenges associated with operations management in small- and medium-sized businesses have been recognized in the operations management literature. As an example, responses to the demands of rapid growth flowing from small-company innovation were addressed by Corbett and Campbell-Hunt (2002). Cultural factors affecting the change management process in the context of small firms' adoption of cellular manufacturing were analyzed by Yauch and Steudel (2002). A taxonomy of small manufacturers based on different competitive priorities was presented by Kathuria (2000), and the adoption of enhanced environmental management in SME's was studied by Lee and Klassen (2008).

The body of operations management literature devoted to SME's is substantial, but many empirical papers devoted to SME issues are focused on specific countries and may lack generalizability. A non-exhaustive review of SME-focused papers that are relevant to the current study is presented below.

Seung-Kuk et al. (2009) used structural equation modeling with survey data to determine that the purchasing function is critical in SME's, and that resource limitations in the purchasing and supply chain management functions result in a disproportionate allocation of time to transaction-specific problem solving to the detriment of strategic sourcing activity. Towers and Burnes (2008) drew on various published sources to develop an overall framework for supply chain alignment in SME's, and found that the focus on short-term problems that characterizes many SME's prevents them from achieving high levels of supply chain integration. Other studies have found that resource limitations in SME's can impede the adoption of new technologies such as flexible manufacturing systems (Petroni and Bevilacqua 2002; Raymond and St. Pierre 2005) and e-commerce (Archer et al. 2008).

Harland et al. (2007) used semi-structured interviews and case studies of 29 companies to determine that SME's may be at the mercy of larger suppliers or larger customers, and may lack the internal resources needed to benefit from high levels of integration with larger trading partners. Archer et al. (2008) conducted a survey of SME managers and found that transaction volume for SME's may be too small to justify high levels of technology-based supply chain integration with larger customers or suppliers. Hudson et al. (2001) used semi-structured interviews to study performance, and found that gaps exist between best practices and the performance measurement systems in use in many SME's.

Yauch and Steudel (2002, 2003) conducted multiple case studies and determined that business-unit specific cultural factors affect the success of significant operations management initiatives in SME's. Corbett and Campbell-Hunt (2002) conducted case studies of growing SME's, and found that key elements of strategy include developing the capability to produce short runs at little or no cost penalty, achieve requisite product variety, provide short manufacturing throughput times, and operate at high levels of quality and delivery dependability.

The magnitude of the strategic challenge identified by Corbett and Campbell-Hunt (2002) is underscored when viewed in connection with the resource limitations that characterize SME's as identified by other papers referenced in this section.

2.3. Supply Chain Integration and Performance Effects

It is widely recognized that achieving a high level of supply chain integration is easier said than done (Swafford et al. 2006). Higher levels of supply chain integration have been associated with improved inventory management (Lee and Billington 1992), better delivery performance (Ahmad and Schroeder 2001), and overall company performance (Frohlich and Westbrook 2001; Flynn et al. 2010). As an example, it has been shown that inefficiencies caused by the *bullwhip effect*, the phenomenon where orders to the supplier have a larger variance than sales to the buyer and the variance is magnified as orders flow upstream, can be mitigated by information sharing of sell-through demand and inventory information across multiple levels of the supply chain (Lee at al. 1997a; Lee et al. 1997b).

Supply chain process variability has been shown to adversely impact enterprise financial performance (Germain et al. 2008). Supply chain agility has been linked to competitive advantage, and to be positively impacted by flexibility in procurement and sourcing (Swafford et al. 2006).

2.4. EOQ-Based Models for Inventory Management

The classic economic order quantity (EOQ) model is widely accepted as a useful foundation for inventory optimization in operations management and related fields. As explained by Erlenkotter (1990), the EOQ model was first developed and presented by Harris (1913), and involved the need to balance inventory costs against order processing costs with the simplifying assumption of constant and continuous demand. Significant papers that detail the development of the EOQ model in the years preceding the emergence of operations management as a distinct academic discipline were published by Raymond (1930), Whitin (1954), and Mennell (1961).

Extensions of the EOQ model to practical applications involving varying demand and lead times are discussed in Silver et al. 1998. The body of published research involving adaptations of the EOQ model is extensive, and a full survey of that literature is beyond the scope of this paper. Significant extensions of EOQ logic that underlie the model presented in this study involved stochastic lead time and/or demand (Liberatore 1979; Silver and Peterson 1979; Eppen and Martin 1988) and the optimization of safety stock levels in a multi-site enterprise (Maister 1976; Zinn et al. 1989).

Although the EOQ model and its extensions are widely understood, qualitative research involving the use of EOQ-based models is relatively rare. Ouellet et al. (1982) presented a case study involving the use of EOQ extensions to reduce safety stock while maintaining service levels in a pharmaceutical company, and Bagchi et al. (1986) published a case study involving the use of EOQ analysis to optimize reorder points and safety stock levels for the U.S. Air Force. Our review of published literature identified an apparent absence of qualitative studies involving the use of EOQ-based models to improve inventory management decisions in SME's.

III. ACTION RESEARCH OVERVIEW

This action research project is focused on a manufacturer of electronic components. These components are used in a wide range of computer hardware devices. The company uses a variety of proprietary product and process technologies, and for that reason the product descriptions and many of the data elements used to describe and test the quantitative model are generic. To protect the company's confidentiality, the company is referred to as "XYZ Company" in this paper.

The initial proposal for this project was an outgrowth of earlier collaboration between the primary researcher and members of the XYZ management team. It became evident that XYZ Company faced a number of supply chain management problems, but lacked the budget to support a commercial consulting study. The researchers regarded the situation at XYZ as an attractive opportunity to conduct qualitative research on decision and change management processes in an SME faced with multiple decision factors and constraints. The researchers' proposal to provide consulting expertise in exchange for access to XYZ Company's management team and archival data for research purposes formed the basis of the working agreement underlying the action research project. The structural attributes of this project are compared to Gummesson's (2000) ten characteristics of action research in Appendix A.

XYZ Company is based in the United States, but it is a wholly-owned subsidiary of a large holding company that is based in Asia. The XYZ supply chain consists of several hundred suppliers, many of which are U.S.-based but some of which are based in Asia or other overseas locations. The focus of the supply chain benefit analysis model is XYZ's relationship with an Asian supplier of engineered raw materials that are used by XYZ Company to fabricate key components of its manufactured products. The Asian supplier is owned by the same multinational holding company that owns XYZ Company, and XYZ is required to source these materials from this affiliated supplier.

The problem addressed by the model is the fact that the replenishment lead times on these key materials is regarded by XYZ management as both excessively long and too unpredictable. The physical transit time on these materials is approximately six weeks, but historical information on the supplier's replenishment lead time resulted in the use of a normally distributed mean lead time of ten weeks, with a standard deviation of 1.67 weeks.

XYZ manufactures a broad variety of similar products, with the technology and customer requirements changing so rapidly that XYZ operates in an engineer to order (ETO) or make to order (MTO) environment without routinely carrying finished goods inventory. XYZ customers demand short delivery lead times, so raw material availability is critical to competitive success for XYZ.

The company's operations management team responds effectively to shifting customer priorities, has undertaken a lean initiative, and has implemented a visually driven pull production environment. But despite a policy that calls for high levels of raw material safety stock, uncertain lead times on critical materials frequently make it necessary to reprioritize and reschedule production orders. This problem has become more severe in recent years as demand for the company's products has grown, and the limited capacity of the existing warehouse facilities prevents the company from carrying additional safety stock.

It is widely understood that small- and medium-sized enterprises (SME's) face many of the same environmental, market, and management challenges as larger companies. At the same time, SME's are confronted by severe limitations regarding funding sources, staffing limitations, and information availability (Lee and Klassen, 2008). A working definition of SME's is that they are too large for entry-level integrated software packages, but too small to absorb the cost and management overhead associated with Tier One enterprise software such as SAP R/3. Although it is owned by a large multinational holding company, the size and control span of XYZ Company, as well as the fact that the company uses a middle-market enterprise resource planning software package, places the company firmly in the SME category. As such, XYZ faces the same challenges as other SME's, including the inability to exercise significant market power over larger material suppliers.

Despite the common holding company relationship, the level of supply chain integration (SCI) between XYZ Company and its materials supplier is low. SCI can provide a sustained competitive advantage by integrating inter-organizational processes to reduce transaction costs (Zhao et al., 2008). With respect to its material supplier, XYZ Company lacks significant expert power, referent power, or reward power (Zhao et al., 2008) to unilaterally change the supplier's delivery lead time commitment. The model presented below is intended to be used by XYZ's management to negotiate a mutually advantageous change of the supplier's delivery practices, or to quantify the benefits and compare these to the costs of alternative unilateral changes that XYZ Company might consider.

While the level of SCI at XYZ Company is low, the degree of supply chain process variability with regard to the affiliated material supplier is high. Supply chain process variability has been defined as inconsistency in the flow of goods through the supply chain, and includes inconsistent delivery performance over time (Germain et al. 2008). Research has shown that supply chain process variability adversely impacts financial performance (Germain et al. 2008). It was understood within the XYZ management team that reducing the variability of their supplier's lead time would be helpful, but the group lacked a mechanism for estimating the economic benefit of reducing this particular form of supply chain process inconsistency.

The long average delivery lead time (ten weeks) for critical materials limits XYZ Company's supply chain agility. Supply chain agility has been defined as the supply chain's ability to respond quickly to a changing market environment (Swafford et al. 2006), and supply chain agility is generally regarded as a key element for improving competitiveness (van Hoek et al. 2001). Research has determined that flexibility in procurement and sourcing processes is a direct determinant of supply chain agility (Swafford et al. 2006). It was understood within the XYZ management team that reducing the average delivery lead time would increase the firm's ability to respond appropriately to changing customer demands in their MTO environment, but the group lacked negotiating leverage with its dominant (and affiliated) supplier.

XYZ's management team recognized the lead time problem, but did not have metrics or reporting procedures in place to quantify its effects. Therefore, this study was undertaken as an offshoot of the action research project. The objective was to develop a model to quantify the lead time problem and provide a tool for use in a cost-benefit analysis. The benefit analysis model would be used to justify an effort to reduce replenishment lead time and/or lead time variability.

IV. PROBLEM FORMULATION

The purchased items that are the subject of this study are engineered materials used in computer peripheral devices. These materials constitute a family of distinct inventory items in a range of sizes and weights that are used in various products manufactured by XYZ Company. The model developed below uses data from one representative item in this family of materials to quantify the economic impact of the proposed changes for that one item. The results for the single item are multiplied by the number of items in the family group to provide a rough-cut estimate of the effect of implementing the proposed changes in replenishment lead time and/or lead time variability over the entire family of materials.

As noted above, the replenishment lead time on key materials sole-sourced from the affiliated Asian supplier is regarded by XYZ management as both excessively long and too unpredictable. The physical transit time on these materials is approximately six weeks, but the analysis of historical information resulted in the use of a normally distributed mean lead time of ten weeks, with a standard deviation of 1.67 weeks.

The company is purchasing the subject materials in container-sized lots, with multiple containers of each material ordered in an average week. While this created a lot-sizing constraint to be honored in the benefit analysis model, the fact that full containers are ordered in the current state scenario yielded the decision to exclude lot sizing and order frequency variations from the model.

XYZ Company's current response to the variability of lead time is a decision rule that says: "Keep the warehouse full." This is intuitively suboptimal, and indeed the analysis presented below shows that historical inventory levels have exceeded the levels required (including safety stock) to meet historic demand with a stockout probability of .025.

The initial management assumption was that the mean lead time may be difficult to change, but that it would be possible for the supplier to reduce lead time variability without incurring significant additional costs. But the decision was taken to analyze different mean replenishment lead times as well as different scenarios regarding lead time variability.

Therefore, the central research question addressed via the supply chain replenishment benefit analysis model is: what is the economic impact, at the enterprise level (as opposed to the extended supply chain level), of excessive replenishment lead time duration and variability?

V. DEVELOPING THE BENEFIT ANALYSIS MODEL

With the problem defined as explained in the preceding section, the chosen solution was the development of a multi-scenario model to quantify the economic benefits (or disadvantages) of a range of average lead time and lead time variability values. The structure, equations, and assumptions used in the model are presented in this section.

Analysis of XYZ's replenishment process and order flow indicated that the company is using a reorder point replenishment system with variable demand and variable replenishment lead time. The equations used in the model are drawn from the presentation on the variable demand/variable lead time situation in Meredith and Shafer (2007), and are detailed in Table 1, below. The following notation is used:

$\overline{\mu}_d$ = Average demand in units per week
σ_d = Standard deviation of demand in units per week
$\overline{LT}$ = Mean lead time in weeks
σ_{LT} = Standard deviation of lead time in weeks
σ_{DDLT} = Overall standard deviation of demand during lead time
α = Acceptable probability of a stockout in any order period
z_α = z-score for the stockout probability (normal distribution 1-tail)
DDLT = Demand during lead time in units
SS = Safety stock
ROP = Reorder point
RT = Reorder target

Values for the following variables are used as input for the model:

- Length of the planning horizon, in weeks
- Number of orders processed during the planning horizon
- Acceptable stockout probability per reorder cycle (the inverse of the service level)
- z-value for the acceptable stockout risk, assuming normally distributed demand
- Product cost/unit
- Historic average inventory level, in number of units of the inventory item
- Number of similar items in the material category
- Weekly demand parameters—mean and standard deviation, in units
- Lead time parameters—mean and standard deviation, in weeks
- Processing cost per order
- Inventory holding cost as a % of inventory cost

Table 1. Equations for Supply Chain Benefit Analysis Model.

DDLT = $\bar{\mu}_d$ x $\overline{LT}$

$\sigma_{DDLT} = \sqrt{\overline{LT}\sigma_d^2 + \bar{\mu}_d^2\sigma_{LT}^2}$

SS = z_α x σ_{DDLT} or z_α x $\sqrt{\overline{LT}\sigma_d^2 + \bar{\mu}_d^2\sigma_{LT}^2}$

ROP = DDLT + SS or $(\bar{\mu}_d$ x $\overline{LT}) + (z_\alpha$ x $\sigma_{DDLT})$

RT = ROP + DDLT or $[(\bar{\mu}_d$ x $\overline{LT}) + (z_\alpha$ x $\sigma_{DDLT})]$ + $[z_\alpha$ x $\sqrt{\overline{LT}\sigma_d^2 + \bar{\mu}_d^2\sigma_{LT}^2}$]

The model was developed in Microsoft Office Excel 2007, which is a widely used and appropriately cost-effective tool for a middle market company such as XYZ. Values for key input variables are entered in an Assumptions section, and calculated output is displayed in a Calculated Values section. The model provides calculated values for the base case and for twelve alternative scenarios. These calculated values are also displayed in output tables and used in graphic exhibits that visually display sensitivity analyses for average lead time and lead time variability.

The benefit analysis model estimates the economic impact of the alternative scenarios at two levels. At each level, the annual operating cost reduction and the one-time working capital savings associated with the projected inventory reduction are compared to historic values under the As Is scenario. The first level is a detailed calculation with respect to a single inventory item. The second level is a rough-cut calculation of the economic impact over the number of similar items in the same product category. This rough cut calculation is performed by simply multiplying the economic results for the single inventory item by the number of similar items in the material category. For more precise results across a range of items, it would be possible to run the model with specific input assumptions for each item in the material category.

The model is designed to be used for multiple scenario analyses, what-if planning, and negotiation support. The model can be immediately recalculated, with the output tables and graphic exhibits immediately updated, when any input value in the Assumptions section of the model is changed.

The Assumptions section and a portion of the Calculated Values section of the benefits analysis model are presented in Appendix B. The model results for the initial run on the base case and twelve alternative scenarios are discussed in the next section.

VI. NUMERIC EXAMPLES AND SENSITIVITY ANALYSIS

The benefit analysis model was run for a total of thirteen scenarios. The demand assumptions are the same for all scenarios, which serves to focus the analysis on changes in average lead time and lead time variability. The first scenario is a modified version of the base case, which uses the base case average lead time of ten weeks and standard deviation of 1.67 weeks, but assumes that XYZ Company can use the calculated reorder point parameters and target safety stock level in lieu of the “keep the warehouse full” decision rule. The remaining twelve scenarios use four alternative average lead times (12weeks, 10 weeks, 8 weeks, 6 weeks) and three alternative lead time standard deviations (1.00, 0.50, 0.10).

Indicative rather than actual values have been used for many of the input variables. This has allowed the model to be tested with sample data while preserving the confidentiality of XYZ Company’s proprietary information. The following values are used as input assumptions for the model:

- Length of the planning horizon: 52 Weeks
- Number of orders processed during the planning horizon: 52
- Acceptable stockout probability per reorder cycle: .025
- z-value for the acceptable stockout risk: 1.96
- Product cost/unit: $2,000
- Historic average inventory level, in number of units: 680
- Number of similar items in the material category: 24
- Weekly demand parameters: mean, 60; standard deviation, 10
- Lead time parameters: as specified for each scenario
- Processing cost per order: $100
- Inventory holding cost as a % of inventory cost: 20%

The model can be rerun for changes in any of the input values listed above. The 52-week planning horizon with 52 orders during the planning period represents a weekly order cycle. This reflects XYZ Company's actual practice, which involves weekly orders in recognition of current inventory levels, actual and expected demand, and previously ordered quantities in transit. The purchase order multiple is equal to a full shipping container load. With the minimum order equal to a full container load, the potential for reducing transport costs by further batching of orders is regarded as negligible.

The acceptable stockout probability is assumed to be .025, and the related z-score value is 1.96. Assuming that demand and lead times are normally distributed, this means that applying the calculated values for demand during lead time and safety stock will be sufficient to meet demand in 97.5% of the reorder periods. The use of a weekly reorder cycle implies that a stockout condition would rarely persist beyond the next week's scheduled delivery. In the interim, the company's buyer/planners can respond by substituting higher-spec material from within the same product family, expediting material deliveries, renegotiating customer promise dates, or altering production schedules.

The assumed product cost per unit of $2,000, the historical average inventory level of 680 units, 24 similar items within the material category, and the weekly demand parameters are values selected to validate the model, and are within the reasonable range of actual historical values for XYZ Company. The processing cost per order of $100 and inventory holding cost at 20% of the related item cost are rule of thumb estimates; these values are used to recognize these costs in the model in the absence of cost studies conducted by XYZ Company to quantify actual values.

The analysis shows that significant performance improvements could be achieved by adopting the reorder point replenishment practices assumed in this model. Adopting the calculated reorder point parameters and target safety stock level in lieu of the "keep the warehouse full" decision rule would yield a projected 25.6% reduction in inventory and inventory carrying costs for the item used in the study—even without reducing the 10 week lead time or the 1.67 week standard deviation of lead time. Further improvements would be possible by reducing either or both of the lead time parameters, as summarized in Table 2, below.

As Table 2 shows, the model indicates that XYZ Company could achieve inventory reductions ranging from 27.2% for the 12-week lead time scenario with standard deviation of 1.00, to a 66.3% reduction for the 6-week lead time scenario with standard deviation of 0.10.

Table 2. Economic Improvement (Detriment) vs Existing Practices Single Inventory Item.

Average Lead Time	Lead Time Variability (Standard Deviation, in Weeks) 1.00	0.50	0.10
12 Weeks			
One-Time Working Capital Reduction-US$	$370,000	$460,000	$502,000
One-Time Working Capital Reduction-%	27.2%	33.8%	36.9%
Annual Operating Cost Reduction-US$	$74,000	$92,000	$100,400
10 Weeks			
One-Time Working Capital Reduction-US$	$494,000	$588,000	$634,000
One-Time Working Capital Reduction-%	36.3%	43.2%	46.6%
Annual Operating Cost Reduction-US$	$98,800	$117,600	$126,800
8 Weeks			
One-Time Working Capital Reduction-US$	$622,000	$720,000	$766,000
One-Time Working Capital Reduction-%	45.7%	52.9%	56.3%
Annual Operating Cost Reduction-US$	$124,400	$144,000	$153,200
6 Weeks			
One-Time Working Capital Reduction-US$	$746,000	$848,000	$902,000
One-Time Working Capital Reduction-%	54.9%	62.4%	66.3%
Annual Operating Cost Reduction-US$	$149,200	$169,600	$180,400

The 12-week scenario implies a longer average lead time than the company is currently experiencing, which implies that it may be worthwhile to trade a longer average lead time for reduced variability. The six-week average lead time scenario can be regarded as the limit of achievable performance improvement, as six weeks is the minimum feasible delivery time using current modes of transportation. Thus, values for the 10-week and 8-week lead time scenarios, which show inventory reductions ranging from 36.3% to 56.3%, can be regarded the range of achievable performance improvements from the initial adoption of new replenishment practices.

In absolute dollar terms, the single-item economic advantages projected for the 10-week and 8-week lead time scenarios range from $494,000 to $766,000 for the one-time inventory reduction and $98,800 to $153,200 for the annual reduction of inventory carrying cost. These values with regard to a single item may be sufficient to justify the costs associated with the required process improvements. The economic impact of the possible lead time and variability reductions over the entire material category (24 similar items), as estimated on a rough-cut basis by multiplying the single item results by a factor of 24, is presented in Table 3, below.

Table 3. Economic Improvement (Detriment) vs Existing Practices Material Category - 24 Items (Rough Cut).

Average Lead Time	Lead Time Variability (Standard Deviation, in Weeks) 1.00	0.50	0.10
<u>12 Weeks</u>			
One-Time Working Capital Reduction-US$	$8,880,000	$11,040,000	$12,048,000
Annual Operating Cost Reduction-US$	$1,776,000	$2,208,000	$2,409,600
10 Weeks			
One-Time Working Capital Reduction-US$	$11,856,000	$14,112,000	$15,216,000
Annual Operating Cost Reduction-US$	$2,371,200	$2,822,400	$3,043,200
8 Weeks			
One-Time Working Capital Reduction-US$	$14,928,000	$17,280,000	$18,384,000
Annual Operating Cost Reduction-US$	$2,985,600	$3,456,000	$3,676,800
6 Weeks			
One-Time Working Capital Reduction-US$	$17,904,000	$20,352,000	$21,648,000
Annual Operating Cost Reduction-US$	$3,580,800	$4,070,400	$4,329,600

In absolute dollar terms, the material-category economic advantages projected for the 10-week and 8-week lead time scenarios range from $11,856,000 to $18,384,000 for the one-time inventory reduction and $2,371,200 to $3,676,800 for the annual reduction of inventory carrying cost. Values in this range for the entire material category would appear to be worthy of a major process improvement effort.

It is useful to analyze the model results to evaluate the relative sensitivity of the economic improvements to changes in the mean lead time as opposed to changes in the variability of lead time. These factors are presented graphically in Exhibit 1 and Exhibit 2 for lead time reduction and variability and variability reduction, respectively.

As the sensitivity analysis shows, the economic performance advantages are more sensitive to changes in the average lead time than to changes in lead time variability. As Exhibit 1 shows, the range of performance improvement is approximately 27-30% across the range of lead times for any given level of variability.

Exhibit 1. Sensitivity Analysis: Inventory Reduction % by Lead Time.

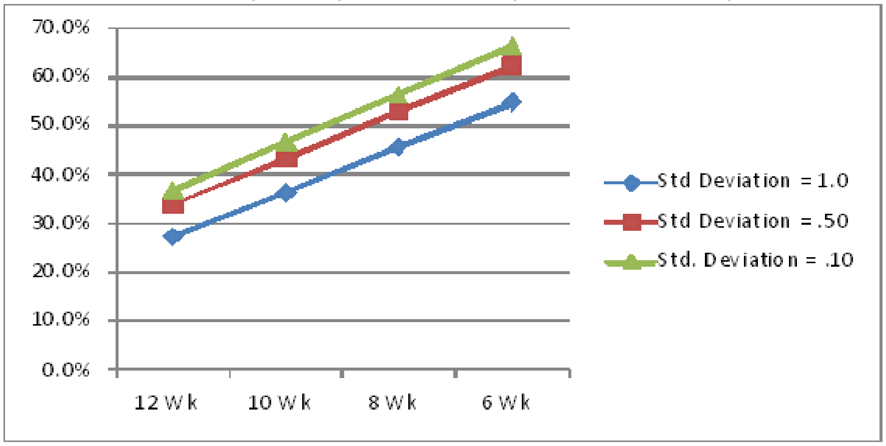
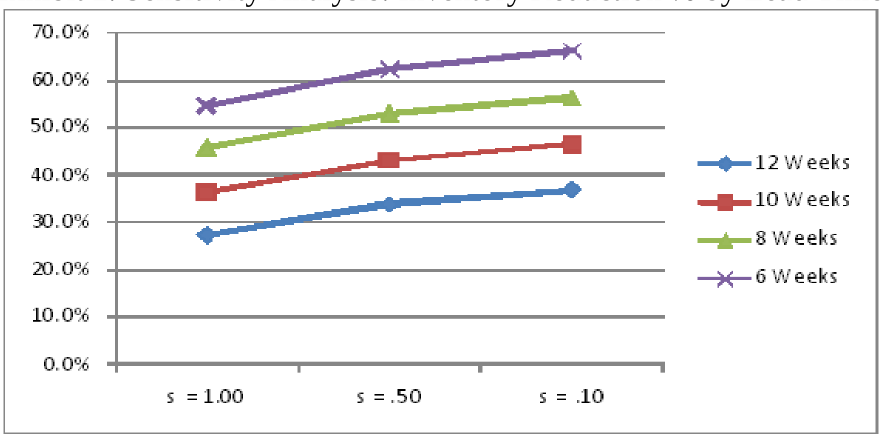


Exhibit 2. Sensitivity Analysis: Inventory Reduction % by Lead Time.



As Exhibit 2 shows, the range of performance improvement is approximately 10-11% for different levels of variability for a given average lead time. This indicates that, although reduced lead time variability is worth pursuing in the absence of average lead time reduction, the optimal objective would be to pursue an absolute average lead time reduction as well as reduced lead time variability.

The next section discusses the significance of these findings, and identifies potential avenues for future research.

VII. RELEVANCE, SIGNIFICANCE, LIMITATIONS, AND FUTURE RESEARCH

The ongoing action research project will yield operational process improvement for XYZ Company, and will support further interpretivist analysis of change management phenomena in XYZ Company. A future research objective will be to use information gathered at XYZ to design and conduct future research regarding change management in SME's.

The following subsections discuss (1) the relevance of the research presented here to XYZ Company management, (2) the significance of this paper's contribution to operations management research, (3) potential extensions of this research, (4) qualitative insights from the action research project that can inform future research on decision and change management processes in SME's, and (5) limitations of this research.

7.1. Relevance to XYZ Company Management

As noted above, the supply chain replenishment benefit analysis model can be used for multiple scenario analyses, future what-if planning, and negotiation support. The model can be used to negotiate with the affiliated supplier—or possibly with the holding company—to secure a commitment to reduce lead time and/or reduce lead time variability. Alternatively, the company can use this model to evaluate any unilateral action that XYZ might consider—such as incurring additional cost to use a faster shipping method or third-party expediting services. The model can measure the benefits for comparison against the cost to achieve various levels of cycle time reduction and/or reduced lead time variability.

Many elements of this research will have ongoing relevance to XYZ's management. The company can use the measures developed in the model as the basis for routine performance metrics, including comparisons of the vendor's actual performance in terms of delivery lead time and lead time variability against committed targets or past performance levels. The company can also monitor its actual average inventory levels and stockout experience against the values projected by the model with a view to adjusting its reorder point or safety stock levels in response to actual experience. The model, and the ongoing metrics based on the model, can also be used to support ongoing process improvement at XYZ Company.

7.2. Significance for Operations Management Research

This research differs from other papers based on reorder point replenishment with variable demand and variable lead time. This paper presents a multi-scenario model with sensitivity analysis capability as a planning and negotiating tool rather than the single-variable optimization model that characterizes most research of this type (Craighead and Meredith 2008). This paper is also distinguishable from other research on reorder point replenishment models in that it is derived from an action research study, which gave rise to the need for, and the pragmatic limitations on the use of, the model.

The model presented in this paper, when used as recommended for decision and negotiation support, offers the relevance to management that operations management scholars have frequently called for (Craighead and Meredith 2008, Meredith et al. 1989, Chase 1981). This approach, and this model, can be adapted for use by companies at any level in a supply chain. The XYZ project deals with affiliated companies under a single holding company, but the method and the model could be readily applied in dealing with arms-length participants in an extended supply chain.

Information provided by the model could be shared with a third-party supplier, at the appropriate point in the development of the relationship, to highlight the cost that the purchasing company is forced to bear when faced with long lead times and/or lead time variability. For companies dealing with a dominant supplier in the absence of a collaborative relationship, the information provided by the model can be used in a cost/benefit analysis to identify unilateral responses that the purchasing company could take to shorten lead times and/or reduce lead time variability—such as alternate vendor selection, different shipping methods, or reliance on third party logistics providers.

7.3. Potential Extensions of This Research

Several opportunities for extensions of this research can be identified. Follow-up on the action research project will include testing and validating the benefit analysis model with actual data. It will be helpful to use actual results to refine the model to increase its predictive power and usefulness as a planning and negotiating tool. First-hand observation of this process will yield additional interpretive information regarding the change management process at XYZ Company, which ideally will lead to the development of new and generalizable theory regarding change management in SME's.

It would also be useful to conduct a fixed vs. variable cost analysis to more precisely quantify the impact of changes in replenishment practices at XYZ Company. The development of a generalizable framework for quantifying inventory carrying costs would be relevant to practicing managers and useful in many facets of operations management research.

Another related research possibility would be a longitudinal action research or case study to follow the progress of XYZ, or one or more similar companies, in pursuing increased levels of supply chain agility and integration using the replenishment benefit analysis model.

7.4. Qualitative Insights from XYZ Company: Future Research Questions

In addition to the possible research extensions discussed above, qualitative analysis of the notes and data gathered at XYZ Company yields three additional research questions. These questions, as presented and explained below, may define future studies of SME decision and change management processes. The first research question addresses the potential usefulness of casting change management initiatives in terms of eliminating an existing problem rather than a cost/benefit investment analysis. The second research question involves identifying significant differences between decision processes followed in SME's that are affiliated with a large holding company vs. decision processes followed in SME's that are independently owned and managed. The third research question involves the possibility of using techniques analogous to those applied in cellular manufacturing to align supply chain management processes with product mix and volume characteristics at the strategic business unit level within a large holding company.

RQ1: Can *cost not to solve* supersede cost-benefit analysis?

Prior to the study detailed in this paper, XYZ Company had considered other actions to address problems associated with excessive lead time and lead time variability. These proposals included the purchase or lease of additional warehouse capacity, and were typically subject to an investment-based cost-benefit analysis.

The analysis that emerged from the action research project essentially turns the cost-benefit analysis on its head. The traditional investment analysis involves quantifying potential benefits in terms of a discounted cash flow stream, and comparing these to the cost of the required investment. In this study, the range of avoidable costs for given reductions in lead time duration and variability are calculated and presented.

We have characterized this as the *cost not to solve* approach to evaluating a change management initiative. This approach has the potential to stimulate corrective action by quantifying an existing problem rather than offering speculative future benefits. The appeal to management is “this is what inaction is costing you today” as opposed to “these are the benefits you might realize in the future if you invest scarce resources now.” Based on our interaction with XYZ Company's management team over the course of the action research project, we believe the cost not to solve approach can be developed further. Future research possibilities include the development of a structured framework for analyzing restructuring or reengineering proposals, and field studies or survey research to evaluate the response of practicing managers to this form of analysis.

RQ2: How do decision processes differ in *nested SME's* vs. independent SME's?

We would characterize an SME like XYZ Company that is part of a larger holding company structure as a *nested SME*. This characterization follows the terminology used by Riketta and Nienaber (2007), who studied perceived compatibility between individual pharmaceutical retailers (nested organizational units) and a large cooperative network the retailers had voluntarily joined.

As noted in the literature survey section of this paper, much of the operations research literature dealing with SME's is focused on specific countries. We have been unable to identify significant research streams in operations management that specifically address the issues faced by SME's that are nested in a larger holding company structure.

Our interaction with the XYZ Company staff and management led us to observe that the company's decision processes involve constraints and limitations that are not present in family-owned or owner-managed SME's. In those companies the supply chain management issues studied here could be presented to decision makers in the course of day-to-day communications. In addition to the geographic, cultural, and linguistic differences separating the U.S.-based XYZ Company from its Asian parent, the company was prevented from using a vendor other than its affiliated sole-source supplier to solve its lead time problems. This gave rise to identifiable employee frustration and morale issues that could affect the company's recruitment, hiring, and retention costs and overall business performance over the longrun.

Future research possibilities include action research, case studies, and/or survey research to identify the nature and extent of differences in the decision processes followed in nested SME's vs. independent SME's. Given access to the necessary archival data, it would also be useful to compare the overall operational and financial performance of nested SME's vs. independent SME's.

RQ3: Can cellular supply chain management boost performance for nested SME's?

Our qualitative analysis of the situation at XYZ Company led us to conclude that the lead time problem is at least partly attributable to a mismatch between the scope and scale of the U.S.-based nested SME and the scope and scale of the affiliated Asian supplier. We found that this mismatch can be understood by applying the Hayes and Wheelwright (1979) product-process matrix.

The product-process matrix identifies a continuum of manufacturing process types ranging from a job shop with low unit volume and high product variability to a continuous flow operation with high unit volume and minimal product variability. Hayes and Wheelwright (1979) discuss a number of strategic decisions that can be made or understood by applying the product-process matrix concept. These include selecting different and appropriate product-process positions for different operating units within an enterprise while maintaining effective overall management control. While the Hayes and Wheelwright (1979) paper is focused on manufacturing processes, the idea of tailoring processes to the product volume and mix profiles of multiple operating units can be extended to supply chain management processes.

That raises the issue of optimizing supply chain processes across the holding company given operating units that occupy different positions on the product-process matrix. This led us to consider the possibility of drawing on the body of knowledge associated with cellular manufacturing to design cellular supply chain management processes at the holding company level.

Hyer and Brown (1999) offer a useful definition of cellular manufacturing: "Dedicating equipment and materials to a family of products with similar processing requirements . . . where tasks and those who perform them are closely connected in terms of time, space, and information." In the case of Asian holding company, the mismatch between the supply chain processing requirements of XYZ Company and those of its affiliated supplier could be optimized by dedicating resources at the holding company level to support or optimize supply chain processes for business units with different product volume and mix profiles.

Schaller (2008) presented a mathematical model that incorporates cellular manufacturing into supply chain design, but we have been unable to identify research that addresses a cellular approach to resource allocation in supply chain management processes. Future research possibilities include the development of a conceptual framework for designing cellular supply chain management processes, survey research to identify the extent to which cellular supply chain management techniques may exist in practice, and action research or case studies to identify emerging best practices in this area.

7.5. Limitations of This Research

Some limitations of this research merit discussion. The benefit analysis model is designed to apply to any situation involving lead time uncertainty in a periodic reorder point environment. The underlying assumptions of relatively stable demand for the raw material item, and normally distributed replenishment lead times, may not be valid for all companies using reorder point replenishment. In addition, the model has yet to be validated by running it with actual data for XYZ Company, and then comparing the model results to actual future experience.

A further limitation is the model's use of a rule-of-thumb calculation to estimate the inventory carrying cost reduction. The use of a blanket percentage value for this purpose is common in operations management (Tang and Teunter 2006; Meredith and Shafer 2007), but it would be preferable to conduct a company-specific fixed vs. variable cost analysis to precisely estimate the economic impact of different replenishment scenarios. At this point no such cost analysis has been conducted at XYZ Company.

Regarding the qualitative analysis of information gathered in the action research project, we recognize the limited generalizability of findings from a single-site study. On the other hand, the potential value of single-site studies for exploratory research is widely recognized (e.g., Dyer and Wilkins 1991). In addition, the researchers' experience in working with other SME's (both nested and independent) reinforces our expectation that the patterns and decision processes identified at XYZ Company are not unique, and that they will emerge to be revisited in in future studies of nested SME's.

VIII. SUMMARY AND CONCLUSIONS

This paper details an action research project that was undertaken to (a) improve supply chain management processes for a mid-market manufacturer of electronic components while (b) extending research on decision processes in small to medium-sized enterprises (SME's). We expect follow-on research to yield new theory regarding change management in SME's.

A supply chain replenishment benefit analysis model, developed to address a problem identified in the action research project, is presented in this paper. The model uses defined input variables to quantify the inventory value and carrying cost reductions for different scenarios regarding the duration and variability of replenishment lead time. Running the model for multiple scenarios with indicative data for the subject company indicates that significant inventory reductions are achievable with the adoption of new replenishment practices.

The supply chain replenishment benefit analysis model can be applied at any level in a supply chain, and will be relevant to any company that faces lead time duration and variability issues in a reorder point replenishment environment. The model can be used in cost/benefit evaluations, for multiple scenario analyses, future what-if planning, and negotiation support.

In addition to extending the limited body of research on the practical application of EOQ-based models, this paper presents qualitative findings from the action research project and identifies research questions to guide the further study of decision processes in SME's.

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Appendix A

Action Research Methodology
Evaluation of the Current Study vs. Gummesson's (2000) Ten Characteristics

Point #	Gummesson (2000) Characteristic	Current Study Attributes
1	Action researchers take action.	The primary researcher led the process analysis and developed the EOQ-based benefit analysis model.
2	Action research always involves two goals: solve a problem and contribute to science.	The study was designed to solve the inventory management problem while allowing the researchers to study SME decision processes.
3	Action research is interactive.	The primary researcher worked closely with the company's management and professional staff, and adapted the study as new information emerged.
4	Action research aims at developing a holistic understanding.	The researchers used qualitative and quantitative information to understand the company's culture, structure, and decision processes.
5	Action research is fundamentally about change.	The study was undertaken to identify and realize process improvement options, and to study the use of information to reach a go-no go decision.
6	Action research requires an understanding of the ethical framework, values, and norms in a particular context.	The primary researcher had previous consulting experience with the company, and brought knowledge of the company's management culture to the project.
7	Action research can include all types of data gathering methods.	The study involved qualitative investigation of the company's culture, structure, and decision processes as well as context-specific use of archival data.
8	Action research requires a breadth of understanding of the corporate environment, business conditions, the structure and dynamics of operating systems, and the theoretical underpinnings of such systems.	The two co-authors bring to this study combined experience totaling over forty years in management, consulting, teaching, and research in operations management and related disciplines.
9	Action research should ideally be conducted in real time.	The study included real-time information gathering and live intervention in the company's activities.
10	The action research paradigm requires its own quality criteria.	The study can be judged by the significance of this paper and the follow-on research that flows from it.

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SUPPLY CHAIN BENEFIT ANALYSIS MODEL
XYZ COMPANY

	ASSUMPTIONS:				
1	Inventory Item Number and Description	10204000	Engineered Material #12		
2	Material Category:	Engineered Materials for Electronic Products			
3	Planning horizon:	1 Year, or 52 Weeks			
4	Replenishment method:	Reorder Point			
5	Number of Orders in Planning Horizon	52			
6	Acceptable Stockout Risk (α)	0.025			
7	z-Value for α (Input)	1.96			
8	Service Level (1-α) One Tail:	97.50%			
9	Product Cost/Unit, USD:	$2,000.00			
10	Historic Average Inventory Level--Units	680			
11	Number of Similar Items in Material Category	24			
12	Demand:	Per Annual Forecast--See Below			
13	Weekly Demand Parameters:	As Is	To Be #1	To Be #2	To Be #3
14	Mean (Units)	60.00	60.00	60.00	60.00
15	Standard Deviation (Units)	10.00	10.00	10.00	10.00
16	Lead Time, Weeks:	As Is	To Be #1	To Be #2	To Be #3
17	Mean	10.00	12.00	12.00	12.00
18	Standard Deviation	1.67	1.00	0.50	0.10
19	Processing Cost per Order (S)				
20	PO and Receipt Processing	$100			
21	Shipping, Freight, Customs	Ignored--cost per full container is unaffected by policy changes.			
22	Inventory Holding Cost %				
23	Includes Cost of Capital:	20.00%	20.00%	20.00%	20.00%
24	Memo—Physical Shipping Time, Weeks:	6.00	6.00	6.00	6.00
25	Memo—Product Stocking Unit of Measure:	EA			
26	Memo—Product Weight, Pounds:	1,000			
27	Memo—Order Multiple (Units/Shipping Container)	40			

APPENDIX B (Page 2 of 2)

SUPPLY CHAIN BENEFIT ANALYSIS MODEL
XYZ COMPANY

CALCULATED VALUES:

28	Annual Holding Cost/Unit (H)				
29	Unit Cost x Holding Cost %	$400			
30	Annual Demand (D)	As Is	To Be #1	To Be #2	To Be #3
31	Total of 52-Week Demand	3,120	3,120	3,120	3,120
32	Average Order Quantity (Q)	As Is	To Be #1	To Be #2	To Be #3
33	Average Order-No Lot Sizing	60	60	60	60
34	Lot Size Adjustment for Ord Mult/Container	0	0	0	0
35	Average Order	60	60	60	60
36	Z-Alpha (One Tail)	1.96	1.96	1.96	1.96
37	Demand During Lead Time (DDLT)	600	720	720	720
38	Standard Deviation of DDLT	105	69	46	35
39	Safety Stock = (Z-Alpha) x (SD of DDLT)	206	135	90	69
40	Reorder point: (ROP)				
41	(ROP) = DDLT + SS	806	855	810	789
42	Reorder Target (RT)—Units /				
43	(RT) = ROP + DDLT	1,406	1,575	1,530	1,509
44	Average Inventory Level—Units:				
45	[(DDLT/2) + Safety Stock]	506	495	450	429
46	As Is Policy (per History)	680	680	680	680
47	Average Cost of Inventory On Hand:				
48	Per As Is Policy	1,360,000	1,360,000	1,360,000	1,360,000
49	Per Replenishment Model	$1,012,000	$990,000	$900,000	$858,000
51	Inventory Working Capital Reduction or (Increase) vs. Base Case	$348,000	$370,000	$460,000	$502,000
52	Annual Order Cost:				
53	Per As Is Policy	$5,200	$5,200	$5,200	$5,200
54	Per Model: 52 Orders/Year * Cost/Order	5,200	5,200	5,200	5,200
55	Ordering Cost Reduction or (Increase) vs. Base Case	$0	$0	$0	$0
56	Average Inventory Holding Cost:				
57	Per As Is Policy	$272,000	$272,000	$272,000	$272,000
58	Per Replenishment Model	202,400	198,000	180,000	171,600
59	Inventory Holding Cost Reduction or (Increase) vs. Base Case	$69,600	$74,000	$92,000	$100,400
60	Total Annual Operating Cost Reduction or (Increase) vs. Base Case--Single Item	$69,600	$74,000	$92,000	$100,400
61	One-Time Working Capital Reduction or (Increase) vs. Base Case--Single Item	$348,000	$370,000	$460,000	$502,000
62	Total Annual Operating Cost Reduction or (Increase) vs. Base Case--All Similar Items	$1,670,400	$1,776,000	$2,208,000	$2,409,600
63	One-Time Working Capital Reduction (Increase) vs. Base Case--All Similar Items	$8,352,000	$8,880,000	$11,040,000	$12,048,000