Book of Abstracts

17th International Symposium on Inventories

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Plenary Lectures

INVENTORY BEHAVIOR WITH PERMANENT SALES SHOCKS

Louis J. Maccini[1], Bartholomew Moore[2] and Huntley Schaller[3]

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Empirically, sales are I(1). We derive a new model of inventories based on this fact. Our theory implies three startling results. First, the variance of production is equal to the variance of sales in the long run.

Second, this result holds regardless of the strength of production smoothing, stockout avoidance, or cost shocks. Third, at business cycle horizons, the conditional variance of production is greater than sales.

Our theory leads to a different way of estimating, testing, and calibrating inventory models. The calibrated model simultaneously accounts for four traditional inventory puzzles and three puzzles about inventories and monetary policy.

THE ROLE OF SUPPLY CHAIN MANAGEMENT INITIATIVES IN ACHIEVING COMPETITIVE ADVANTAGE

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Supply chain management (SCM) practitioners and academics have long contended that SCM initiatives can help create a competitive advantage for a firm in the manufacturing and/or merchandising industries. Anecdotal evidence, however, suggests that most chief executive officers (CEOs) do not recognize nor understand this. Using existing literature and real-world examples, this research explores the ways firms create competitive advantage and the potential role of SCM initiatives in enhancing these strategies.

We begin with a review of the literature on corporate strategies. Firms create competitive advantage through a whole set of activities. Individual firms may differentiate themselves by doing the same activities as competitors in different ways, or by performing different activities. Firms may also create entirely new markets and products through innovation. The supply chain initiatives appropriate for each of these approaches will differ. We give examples of existing firms that operate effectively in each of these arenas to illustrate these differences. We conclude that cross-functional and cross-firm initiatives are critical in building competitive advantage, and that it is the cumulative effect of sustained supply chain innovations over an extended period of time that leads to success.

Keywords: supply chain management, corporate strategy, supply chain strategy, competitive advantage

FORECASTING INTERMITTENT DEMAND FOR INVENTORY MANAGEMENT

Ruud Teunter

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Intermittent demand is characterized by long intervals without a demand, and often lumpy demand sizes if a demand does occur. Such difficult (to forecast) demand patterns are quite common in any industrial setting and especially prevalent in service logistics, and can account for more than 50% of total stock value. Most firms use traditional techniques such as moving average and simple exponential smoothing for forecasting intermittent demand. Although these methods may provide reasonably accurate estimates for the demand per period, I will argue in this presentation why they are not suitable for inventory management. I will then introduce some methods that have been specifically developed for forecasting intermittent demand, including Croston's method, the SyntetosBoylan Approximation (SBA), and the more recently proposed TSB and 2-step method, discussing their pros and cons and showing empirical results. I end by indicating a number of opportunities for future research.

MANAGING ENERGY STORAGES – LESSONS FROM INVENTORY THEORY & RESEARCH AGENDA

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The redirection of Energy Policy towards sustainability significantly increases the share of renewable energies (e.g. 30% by the year 2020 in Germany) but the complexity of matching demand with supply increases due to multiple sources and increasing uncertainty of supply. Increasing the efficiency of energy systems and to account for high fluctuations in energy supply and demand not only requires advances in generation and storage technologies but also in the management of the associated operations processes.

Energy storages are a core ingredient of a sustainable energy grid to decouple dynamic and uncertain, highly fluctuating supply of and demand for energy from different sources and at regionally dispersed locations. Where the majority of research is devoted to invent and improve storage technologies, efficiency increases might not only be achieved by enhanced technological capabilities but also by a more effective management of supply and demand.

Inventory theory offers a broad spectrum of models, approaches, and methods to manage reservoirs and storages where only few contributions were devoted to energy due to its limited storage ability. The advice and decision support that existing knowledge can provide, and necessities of tailoring models to energy system specialties, will be reviewed and discussed in this presentation. A framework for advanced energy supply chain planning and management will be presented. Besides an overview on short- and long-horizon storage technologies and their characteristics, core ingredients are the modeling of demand, price and supply processes, especially the problem of intermittency of renewable solar and wind energy supply; multiple modes of stochastic and controllable supply; reservoir and storage capacity planning and multi-location coordination in smart grids; storage management policy structure and parameter determination methods; and decaying inventory and random yield due to storage and transmission.

DYNAMIC DEMAND FULFILLMENT IN SPARE PARTS NETWORKS WITH MULTIPLE CUSTOMER CLASSES

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We study real-time demand fulfillment for networks consisting of multiple local warehouses, where spare parts of expensive technical systems are kept on stock for customers with different service contracts. Each service contract specifies a maximum response time in case of a failure and hourly penalty costs for contract violations. Part requests can be fulfilled from multiple local warehouses via a regular delivery, or from an external source with ample capacity via an expensive emergency delivery. The objective is to minimize delivery cost and penalty cost by smartly allocating items from the available network stock to arriving part requests.

We propose a dynamic allocation rule that belongs to the class of one-step lookahead policies. To approximate the optimal relative cost, we develop an iterative calculation scheme that estimates the expected total cost over an infinite time horizon, assuming that future demands are fulfilled according to a simple static allocation rule. In a series of numerical experiments, we compare our dynamic allocation rule with the optimal allocation rule, and a simple but widely used static allocation rule. We show that the dynamic allocation rule has a small optimality gap and that it achieves an average cost reduction of 7.9% compared to the static allocation rule on a large test bed containing problem instances of real-life size.

Keywords: inventory, spare parts, dynamic demand fulfillment, multiple customer classes

DURABLE GOODS PRODUCTION AND INVENTORY DYNAMICS: AN APPLICATION TO THE AUTOMOBILE INDUSTRY

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This paper develops a model of the joint determination of production, inventories and pricing of a monopolistically competitive durable good producer. The model gives rise to time varying markups that interact with the inventory-sales ratio, even with flexible prices. Maximum likelihood estimation with automobile industry data yields plausible parameter estimates and impulse responses. We then apply the model to analyze the impact of the "Cash-for-Clunkers" program, and find that the model predicts a negligible production response; essentially all the action is inventories. This leads us to consider evidence of threshold effects that imply a stronger response very far from the steady state. This results in a modest but more plausible production response to the policy-still modest in comparison to the sales impact, but now at least measurable. Even with some production response, the results still provide a cautionary tale for countercyclical policies that rely on stimulating consumer spending. Even an impact on spending need not translate into a comparable impact on employment and output.

The views expressed in this paper are those of the author and do not necessarily reflect the views of the Federal Reserve Bank of New York or the Federal Reserve System.

Economics of Inventories

SALES, INVENTORIES, AND REAL INTEREST RATES: A CENTURY OF STYLIZED FACTS

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We use Bayesian time-varying parameters structural VARs with stochastic volatility to investigate changes in both the reduced-form and the structural correlations between business inventories and either sales growth or the real interest rate in the United States during both the interwar and the post-WWII periods. We identify four structural shocks by combining a single long-run restriction to identify a permanent output shock as in Blanchard and Quah (1989), with three sign restrictions to identify demand- and supply-side transitory shocks. We produce several new stylized facts which should inform the development of new models of inventories. In particular, we show that (i) during both the interwar and the post-WWII periods, the structural correlation between inventories and the real interest rate conditional on identifed interest rate shocks is systematically positive; (ii) the reduced-form correlation between the two series is positive during the post-WWII period, but in line with the predictions of theory it is robustly negative during the interwar era; and (iii) during the interwar era, the correlations between inventories and either of the two other series exhibits a remarkably strong co-movement with output at the business-cycle frequencies.

Keywords: Bayesian VARs; stochastic volatility; time-varying parameters; structural VARs; long-run restrictions; sign restrictions; inventories; monetary policy; monetary regimes.

JEL codes: C11; C32; E32.

The views expressed in this paper are those of the authors and should not be interpreted as those of the Federal Reserve Bank of Richmond or the Federal Reserve System.

PRODUCTION CHAINS, DEMAND, AND OUTPUT VOLATILITY IN THE DURABLES SECTOR: 1967-2011

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The economics profession has strived to explain the sudden, substantial, and longlasting stabilization of GDP that occurred in the mid-1980s–the so-called "Great Moderation." One explanation is that the stabilization is due to improved inventory management techniques. There is large body of evidence to support the observation that durables production stabilized and durables inventories stabilized. The question addressed here is whether these observed improvement can be attributable to changes in the demand for durables, specifically, less persistent shocks.

To address this question, the durables manufacturing sector is modeled as a production chain consisting of firms that produce to order and firms that produce to stock. Output movements are driven solely by shocks to final demand. Separate demand models are estimated over four separate sub-samples spanning the 1967-2011 period. Simulations indicate that changes in the volatility of output can be explained as a by-product of changes in demand behavior without appealing to innovations in production management. The best evidence of innovations in production management that remains are declines in work-in-process and unfilledorders that began in the 1990s–well into the Great Moderation.

INVENTORIES IN NATIONAL ECONOMIES: A CROSS COUNTRY ANALYSIS OF MACROECONOMIC DATA

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In the paper we compare long term macroeconomic inventory behavior of various countries and by studying the explanations of the differences we obtain information on general factors influencing this behaviour. As a comprehensive indicator of macro level inventory formation, we use the inventory investment/GDP ratio, which shows what proportion of the new value created in the economy in a given year is invested in inventories.

Our previous research (for a brief summary see Chikan - Kovacs (2009): Inventory investment and GDP characteristics in OECD countries. International Journal of Production Economics 118, 2-9.) suggests that behaviour of any economy shows some long term characteristic features which prevail over the short term fluctuations. These features serve as kinds of distinctive „norms" in any economy and we get very useful knowledge if we can explain the influencing factors of these norms. The long term inventory investment/GDP ratio is that kind of a norm.

We use a set of macroeconomic indicators to explain inventory behaviour, mostly based on GDP statistics. Shortcomings of these statistics of course put limit on the reliability of our results – however this is still a defensible (but of course not the only) way of studying macro inventory behaviour. We analyze 20 year time series of inventories in a set of developed countries, and disclose their relationship to growth, to industry structure and to alternative uses of GDP (fixed capital investments, foreign trade and consumption).

Besides traditional regression analysis we apply multivariable statistical methodology, mainly factor- and cluster analysis of macroeconomic data.

THE ROLE OF INVENTORIES IN THE GREAT RECESSION AND THE RECOVERY

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The paper examines in a non-technical way the role of inventories in (triggering or aggravating) the 2008-2009 great recession and in the ensuing recovery. It shows how a policymaking institution can usefully take into account inventory developments, marrying evidence from both national accounts and surveys, at the euro-area (and countries) level but also at the global level.

In particular, it is:

(1) examining the hypothesis of an "inventory shock" following Lehman,

(2) documenting the role played by the composition of inventories (those controlled, and those not controlled), leading to a "circulation" of inventories across the economy, along the supply chain,

(3) in this context of such a "circulation of inventories" across borders, illustrating the role played by the links between inventories and external trade, emphasising the impact of globalised supply chains, with a specific focus on the non-negligible inventories in transit (stocks at sea),

(4) highlighting the linkages between inventories and financing conditions, at a time of strive for cash, with some elaboration on the link with short-term bank lending as well as trade credit,

(5) examining the merit of a inventory-to-GDP ratio rule for forecasting.

THE ECONOMICS OF MEMBERSHIP BASED LOYALTY PROGRAMS

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Many online retailers use membership based loyalty programs to attract customers. A typical advantage of using the program is a discount in shipping and delivery charges. For example, Amazon, an online retailer selling almost everything from books to electronics offers a program called "Amazon Prime." For an annual fee of $79, customers can get free "2-day shipping" on many key items and free "standard shipping" on many more.

On one hand, the premise of such loyalty programs is that it will increase the order value of each customer -- that is each member of the program will spend more with the program than without. On the other hand, online retailers have to plan for the availability of the product and absorb the shipping and distribution costs for the customer. For example, a recent report by Piper Jaffray, a leading investment bank and asset management firm in the USA, estimates that Amazon's Prime members outspend non-members by 130% and each member's "spend" growing from $400 annually to $900 annually!

In this paper, we provide an exploratory model for analyzing such "free shipping" loyalty programs. We explicitly analyze the tradeoffs between the revenues generated by membership fees and how it can potentially be offset by shipping and distribution costs on each order to the customer. The more often a customer orders from the retailer, the value for both the online retailer (via increased spend) and the customer (can get full value from the program) increases. On the flip side, more orders, especially on low margin items, also means the retailer can potentially loose money on certain customers. The model is unique in two ways. First, it uses a total cost model that explicitly considers the various revenues and costs of the program; and second, through an optimization & simulation analysis, shows how the model can also be used as a template to design such membership loyalty programs.

COORDINATED DYNAMIC PRICING AND ORDERING DECISIONS FOR PERISHABLE PRODUCTS WITH MULTIPLE DEMAND CLASSES

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This paper focuses on the coordination of the dynamic pricing and ordering decisions of a perishable product, where the product has a lifetime of two periods. Hence in any given period, the inventory may contain products with two different ages. The new product is sold at the retail price while the old product is sold at a discounted price. We assume the demands for two different ages of products come from two demand classes which are independent of each other. Moreover, the demand for the old product is dependent on the discounted price which we allow to change. We compute the optimal order quantity of new product and the optimal discounted price for old product given the remaining inventory level of old product in order to maximize the total profit. We first show that under certain conditions, the total profit is a concave function with respect to the order quantity and this enables an efficient algorithm to be developed to compute the optimal order quantity. We also prove that the dynamic pricing model always outperforms the static pricing model. Finally, we extend our results to a more general case where the product has an N-period lifetime.

Keywords: inventory; dynamic pricing; perishable product; periodic review; multiple demand classes

TIME TO PRODUCE AND EMERGING MARKET CRISES

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The opportunity cost of waiting for goods to be produced and sold increases with the cost of financing. This channel is evident in emerging market crises, when industries that use more inventories lose more of their output and lag behind in the recovery. An open economy model with lags in the production process („time to produce") generates comparable cross-sectoral differences in response to a shock to the foreign interest rate and, in the year of the crisis, accounts for up to 25% of the deviation of output from its previous trend. In contrast, an equivalent model without time to produce generates a boom in the year of the crisis and cannot account for the cross-sectoral differences. Likewise, it is impossible to generate the cross-sectoral differences in response to a productivity shock.

JEL classification: E22, E23, F41

Keywords: cost channel, sudden stops, time to build, crises, inventories, emerging markets

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STRATEGIC INVENTORY AND SUPPLY CHAIN BEHAVIOR

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Supply chain coordination via contracts has received ever-increasing attention in the recent past. Typically, studies in this research field focus on one-period settings. Yet, current research is showing that the predictions regarding the coordination power of contracts may be altered in multi-period contexts, which are often observed in a supply chain environment. The present work empirically tests how a serial supply chain performs under simple whole-sale price contracts in a 2-period setting with price-sensitive end-customer demand. In such an environment, theory predicts that – even if no operational reasons for stock-holding exist – the buyer builds up strategic inventory in order to limit the supplier's monopoly power as long as inventory costs are not prohibitively high. Therefore, in the case of a simple wholesale price contract, strategic inventory leads to higher supply chain efficiency by lowering the supplier's average wholesale-price and, in turn, reducing the well-known double marginalization effect.

The laboratory investigation validates the theoretical predictions to a large extent. As accurately predicted by standard theory, strategic inventories are too costly and not observed for prohibitively high holding cost levels. For reasonable holding cost levels, in turn, strategic inventories indeed play a major role in the supplier-buyer interaction. In contrast to standard theory's predictions, though, it is shown that outcomes are only accurately predicted, if reciprocity concerns and reciprocal actions are incorporated into the standard model. In the experiments, the supply chains under consideration are performing even better than expected, because the supplier lowers the average whole-sale price, while the buyer builds up less strategic inventories than in the theoretical benchmark. We conclude that the impact of double marginalization is overestimated, if reciprocity concerns and reciprocal actions are not considered in the analysis.

Keywords: strategic inventory, experimental economics, behavioral economics, supply chain coordination, fairness

Inventory Management

THE SINGLE PERIOD INVENTORY MODEL WITH PRODUCT CARBON FOOTPRINT CONSTRAINT

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The need for integrating environmental measures in operational decision making has been strongly emphasized in recent years. There is growing consumer awareness for the environmental impact of products, and there are regulations related to carbon emissions of companies' activities. Additionally, there is intrinsic motivation of companies and managers for doing better in terms of environmental sustainability. While an immediate action following these drivers is adopting greener manufacturing and transportation technologies, there is still an opportunity of doing environmentally better by redesigning operations considering environmental criteria besides economic criteria. Specifically, including environmental impact of production, transportation, and inventory decisions in the planning and optimization models is required in order to create environmentally responsible business operations. This can be done for an organization or for a supply chain sometimes including consumption and recycling or disposal. The carbon (equivalent) emissions of a product for all supply chain operations is called product carbon footprint.

In this study, we present a single period inventory control model including a constraint for the product carbon footprint. This might be seen as reaction to public pressure coming from increased consumer awareness which is of relevance in the food and clothing industries. The product carbon footprint includes all product-related production, transportation and warehousing operations. In the basic framework also the additional emissions related to over-stocking, for example for shipping of leftovers to secondary markets or disposing them of, are formulated explicitly. This includes the scenario of a buyback contract. If in case of under-stocking a second ordering opportunity exists, then the resulting carbon emissions must also be considered. In this dual sourcing situation the inventory manager has different options causing different emissions. First the same procurement channel can be used, second a faster transportation mode can be chosen in case of an offshore supplier with a long transportation distance. A third option is that the goods are produced by an onshore supplier. We develop analytic insights in dependence of the profitability of the product, its variability of demand and its carbon footprint and present the implications of the carbon footprint constraint for the investigated operations strategies (buyback contract, dual sourcing).

Keywords: inventory, newsvendor, environmental constraint, product carbon footprint

BUYER-SUPPLIER COORDINATION FOR CONTINUOUSLY STOCKED ITEMSVIA RETAIL PRICINGAND REVENUE SHARING

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Supply chain coordination through various mechanisms, towards deriving globally optimal solutions, has received substantial research attention in recent years. This paper examines a two-echelon supply chain consisting of a single supplier (manufacturer) and a single buyer (retailer), where the former manufactures and delivers several products that are stocked and sold by the latter on a continual basis. The supplier produces these products in a batch production facility, which can produce only one item at a time. The manufacturing batch size of a product is an integer multiple of the lot size ordered by the buyer. In other words, an item's production batch is completely depleted through an integer number of equal sized deliveries at equal intervals to the buyer. At the retailer's end, the market demand for each item is dependent upon its retail price. Two cases of price-demand relationships, i.e. linear, and isoelastic non-linear functions, are adopted in our analysis. We first develop infinite horizon profit models for the buyer and the supplier under a decentralized scenario, where the two parties do not cooperate and their decisions are not coordinated. In this case, the retailer sets the retail price of each product and its order quantity, towards maximizing its own total gross profit. In response to the retailer's orders, the manufacturer then determines the production batch size of each product for maximizing its own overall gross profit. For simplicity, we assume that the supplier adopts a common rotational cycle production policyfor dealing with the manufacture and delivery of the multiple items in question. We then construct a centralized model for the entire supply chain, where the two parties cooperate and jointly derive the retail pricing, purchase order quantity and production batch sizing decisions for the various products concerned. We show that the centralized coordinated scenario yields higher gross profit for the supply chain as a whole. For the purpose of achieving such coordination, a revenue sharing mechanism is suggested, so that the two parties share the resulting surplus in a fair and equitable manner. Finally, through a set of numerical examples, we demonstrate the concepts developed in this paper and examine the sensitivity of our solutions with respect to a selected set of problem parameters.

Keywords: buyer-supplier coordination, pricing, revenue sharing

INVENTORY LOCATION AND TRANSSHIPMENT PROBLEM

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We analyze an inventory location problem where facilities are allowed to satisfy some of the demand by transshipping available inventory between each other and customers may change the shopping patterns based on stock availability at the facilities. These features make the model significantly more difficult than either the inventory location or transshipment models in the literature.

By applying Infinitesimal Perturbation Analysis (IPA) algorithm – a form of approximate dynamic programming we show how realistic-size versions can be solved and obtain some interesting managerial insights.

DERIVING RESEARCH AGENDAS FOR MANUFACTURING AND LOGISTICS SYSTEMS: A METHODOLOGY

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Changes in the business environment often require consequential economic, environmental, technical and social adaptation by manufacturing and logistics organisations. The objectives of this study are to develop a methodology to help manufacturing and logistics systems analysts identify and prioritise an organisation's problems and so determine the changes that need to be made. The problems and associated investigations form the research and implementation agendas.

The methodology considers a company's manufacturing system functions to be part of a concurrent enterprise and then uses the concurrent enterprise model in conjunction with an unconstrained Activity Matrix. The first step of the methodology is to construct the concurrent enterprise (CE) representation of the manufacturing organisation and to identify the activities that the organisation uses to introduce and produce its products and systems. To assess where changes may be required, the analysis considers the manufacturing system's activities over a product's life cycle and examines how they affect the system attributes or outcomes. An Activity Matrix (AM) shows the system activities that convert physical inputs and plans (stated or implied) into the attributes chosen by the systems analysts to measure the system performance. Potentially, the methodology has wide applicability.

The methodology is illustrated by producing a research agenda for Production Planning and Control (PPC). The paper also outlines some other fields in which the methodology could be used. The methodology uses the Activity Matrix (AM) to produce a Problem Matrix (PM) from which is produced a Tentative Research Matrix (TRM) from which is developed the Research Matrix (RM). The RM activities are then prioritised to create the research agenda (RA).

AM=>PM=>TRM=>RM=>RA

Keywords: research agendas, activity matrix, manufacturing and logistics, concurrent enterprise, life cycle

A HEURISTIC APPROACH TO THE INVENTORY POOLING AND ROUTING PROBLEM

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Inventory Pooling and Routing Problems (IPRP) are on the interface of inventory control and transportation. As the name suggests, IPRP are closely related to both Inventory Routing Problems (IRP) and problems in which inventory is pooled among retailers. Pooling models focus on finding optimal order quantities and moments of redistribution such that total inventory costs are minimized. However, existing models neglect transportation costs in the sense that they do not look into the different routes that could be used for pooling stock. IRP aim at finding optimal order quantities and routes for distribution but do not allow for pooling. IPRP combine both problems and try to minimize the sum of inventory and transportation costs by looking at optimal order quantities and routes for (re)distribution while pooling is allowed. Although both IRP and inventory pooling are widely discussed in literature, little is known about IPRP. In a first explorative study, we focused on the pooling policy and used a route for redistribution that is fixed from the outset. In this talk, we will focus more on the routing aspects of the problem.

We consider a single period setting with N retailers that are served by a single warehouse. At the beginning of the period, retailers are replenished with their order-up-to levels. Demand at the retailers is uncertain and retailers face backorder costs for each unit of demand which cannot be satisfied immediately, and holding costs for each unit which remains unsold at the end of the period. At a predetermined point in time, the warehouse has the opportunity to pool stock among retailers in order to reduce inventory costs. However, pooling stock comes with certain transportation costs which depend on the distance between retailers. We assume that we know residual stock levels of the retailers at the moment of redistribution. Given these residual stock levels, the expected demand in the remainder of the period and the distances between retailers, we look into the question whether and how to rebalance stock levels. As the problem is NP-hard (we need to solve a Vehicle Routing Problem to find the optimal route), we first look into the case with only a few retailers such that we can solve the problem to optimality by complete enumeration. Next, we develop a heuristic solution method for the case with multiple retailers. Using the exact results for the case with few retailers, we can analyze the quality of the heuristic method.

ANALYSIS OF SUPPLY CONTRACTS WITH A MINIMUM QUANTITY COMMITMENT AND FIXED ORDER COSTS

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Standard periodic review, stochastic, inventory models assume a per-specified purchase cost and allow the buyer to place orders periodically. In most of these models, there are no restrictions placed on the buyer regarding quantities to be purchased. Therefore, such procurement arrangement represents a contract form that is the most flexible for the buyer. However, in practice, many contracts do impose certain restriction on the buyer. One of such restrictions takes the form of commitments by the buyer to purchase a minimum total (cumulative) order quantity over a planning horizon (e.g., one year). In return, and the supplier agrees to sell the item for a discounted price. However, the timing of each individual replenishment order is up to the buying firm. This talk considers a setting in which each replenishment order incurs both fixed and variable costs. The objective is for the buying firm to minimize the total expected cost over the contract horizon by optimally determining the replenishment policy. Using a new state transformation method, we are able to show the optimal policy to be of a modified (s, S) form.

COMPANY COMPETITIVENESS AND INVENTORY PERFORMANCE

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This research discusses the link between company competitiveness and the inventory performance of the company. Unfortunately this question is not very well addressed in the literature, though we think that inventories significantly affect the whole operations of the company (not just the manufacturing function).

We apply a two-step approach to map and test the relationships among the variables. First we use Bayesian networks, then structural equation modelling (SEM) using PLS method to investigate the effect of inventory-related variables and inventory performance on company competitiveness. (Wu, 2010; Henseler et al., 2009). Inventory performance variables reflect the role of inventories in the companies life from different aspects (e.g. average turnover rate, importance of inventory management, extent of computer system integration). For the inventory-related variables we have a supply chain concept in mind, and we include variables that are importantly linked to inventories (e.g. throughput time efficiency, adequate level and mix of inventories, financial factors, top management's job related to inventories). Company competitiveness is based on variables that measure operability, ability to change and market performance. (Chikán, 2006) Data were acquired through the 4th round of the Competitiveness Research Project executed in Hungary in 2009 in the manufacturing industry with a sample of more than 120 firms and 400 respondents (on average approximately 3.5 respondents per firm).

We expect to find inventory performance variables and inventory-related variables that significantly influence company competitiveness. We discuss the managerial implications of this result and also give ideas for further inventory research in the context of company competitiveness.

Keywords: company competitiveness, inventory performance, Bayesian networks, SEM

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SUPPLY CHAIN COORDINATION THROUGH RISK SHARING CONTRACTS UNDER DIFFERENT FORMS OF YIELD UNCERTAINTY

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The various actors in a supply chain (SC) usually make their decisions based on individual profit maximization. Generally, such behavior leads to efficiency losses for the SC as a whole. By coordinating individual decisions, however, those efficiency losses can be avoided. In this context, appropriately designed contracts can coordinate the SC, i.e. they set incentives which induce the decision makers to deviate from their initial goal to maximize own profit towards SC optimal behavior. In cases where the SC suffers from supply uncertainty occurring, e.g. as random production yield or transportation disruption, the complexity with respect to decision making and contract design amplifies. This complexity mainly results from the specific nature of risk distribution in a SC which faces supply uncertainty. While in the newsvendor setting demand uncertainty only concerns the retailer, under supply uncertainty the supplier as well as the next downward SC stage are affected by the risk of unreliable production or transportation. Only recently and to a rather small extent the topic of SC coordination under stochastic production yield has been dealt with in literature. Moreover, the research field of SC coordination under disruption risk has not been dealt with at all. In this context, literature rather focuses on SC coordination in demand disruption settings.

In our setting, a serial SC with one supplier and one buyer is considered where the buyer, who faces deterministic demand, orders from the supplier who in return decides on a production quantity and delivers to the buyer. In this single period interaction, two forms of yield uncertainty are considered separately. The first analysis deals with stochastically proportional yield where production output is a random fraction of the input quantity. The second model incorporates the risk of disruption. Here, production output is equal to input with a certain probability while the output is zero with the complementary probability. For both models, the intention is to analyze the ability of known risk sharing contracts to coordinate the SC. The contracts under investigation are the simple wholesale price contract, a penalty contract and one that defines risk sharing in case of overproduction at the supplier. It can be shown that for each setting, at least one of the contracts can achieve coordination of the SC.

EVALUATION OF AN INFORMATION SYSTEMS INVESTMENT INTO REDUCING THE BULLWHIP EFFECT

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Objectives of study: This paper presents a methodology for the profitability evaluation of an information systems investment into reducing the bullwhip effect in the supply chain.

Materials and Methods: Bullwhip effect is commonly caused by fully rational actors in a supply chain locally optimizing their situation. The effect causes especially the upstream companies to suffer. There are remedies to the bullwhip effect that are based on increasing the information flow throughout the supply chain. There are also models that show that the increased information will aid in the optimization of the entire supply chain. These remedies often require an information systems investment.

When an information system that allows collaborative sharing of information about the whole supply chain is introduced, the new information allows the actors to reach savings by, for example, reaching reductions in inventory. Other benefits in reducing bullwhip effect may include decrease in production overtime, increased customer satisfaction, and reduced lead times.

Results: To reach the savings the supply chain actors must make an investment in an information system. The investment will take place if it is perceived to be profitable. Being able to evaluate the profitability, when information about the reachable benefits is vague and imprecise, requires specialized methods: for this reason a fuzzy method the pay-off method is used in the analysis. The pay-off method is a recent addition to the toolkit of managers for the evaluation of investment profitability and will be used in this paper to achieve the result of analyzing the profitability of an information system.

Conclusions: The Bullwhip effect costs serious money, but can be counteracted through smart decision making using collaborative methods. However, these remedies are not easily estimated. Therefore a fuzzy pay-off method is applied into the Bullwhip context. This paper will also show that the investment into smarter information systems can lead to an improved inventory and supply chain performance.

Keywords: bullwhip effect, supply chain, information systems, pay-off method

SEQUENCING METHODS FOR STORING AND RETRIEVING INVENTORIES

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Inventories are often kept in warehouses, where automatic storage and retrieval systems (AS/RS) are being used. An AS/RS has the advantage that tighter aisles can be used and the space can be used more efficiently. Usually, there is one crane per aisle. The aim of the study is to analyse the effect of having multiple cranes in a single aisle to allow for increasing the speed of storing and retrieving inventories. Since the cranes are not able to pass each other, this implies that each crane has its own area in the aisle. Consequently, we have to prevent the cranes from clashing. We translated this problem into a linear programming problem (for any number of cranes more than 1) and designed a heuristic (for two cranes). Both models have the aim of determining the order of handling storage and retrieval requests in such a way that the total time needed is minimized. The maximum savings we reach with our heuristics are up to 50% by using two cranes per aisle. So, we may conclude that having more than one crane per aisle does save time.

Keywords: inventory management, warehousing

BEHAVIORAL ANALYSIS AND ADAPTATION OF A NEGOTIATION BASED, QUANTITATIVE PLANNING APPROACH FOR HYBRID ORGANIZATIONS

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Increasing product complexity, dynamic markets, and geographic dispersed customers and factories require flexible decentralized organizations. Even though in those organizations the headquarter's influence is reduced, the alignment of the decentralized sites on the global goals of a company is still necessary for improvement of efficiency. Therefore a central instance (headquarters, central planning department) has to determine the basic conditions of the decentralized planning processes. The coordination of the (quasi-)autonomous decentralized sites is based on negotiations considering these conditions. Even if some few planning approaches have been presented (Kouvelis/Gutierrez (1997)) for this situation, those models have not been analyzed for the case, that decision makers do not act according to the relevant assumptions, such as risk neutral rational behavior. The results of some laboratory experiments reveal deviations between model assumptions and human behavior for some models (Schweitzer/Cachon (2000)). The deviations might be caused by incomplete information or personal characteristics of the negotiators, such as the risk preference.

The aim of this paper is the introduction of adaptations for a hybrid planning approach in multi-location newsvendor situations (Oberlaender/Dobhan (2010)) with a special focus on behavioral aspects. The adaptation is based on a detailed analysis of the robustness of hybrid planning, considering the (empirically observed) behavior of decision makers.

We, therefore,

- analyze the results of the hybrid approach for different behavioral patterns,
- examine, how the planners' behavior, which differs from the model assumptions, influences the planning results,
- introduce a new approach or rather adapt an existing approach to improve the robustness concerning human behavior,
- describe a design for a laboratory experiment in order to get empirical evidence for the benefits of the hybrid approach.

The main effort of the paper is the mapping and integration of different behavioral patterns. The results indicate that even if we assume varying behavior, the (adapted) approach induces good results. It is therefore an appropriate alternative to existing approaches and models.

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JOINT DESIGN OF LGV PALLET SHUTTLE FLEETS FOR WAREHOUSE AUTOMATION

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This paper deals with emerging automation technologies for pallet handling in multi pallet-deep rack storage systems. In particular, this study investigates opportunities resulting from the adoption of pallet shuttles (PSs) for material handling within the rack structure, i.e. for put-away and retrieval operations from the rack face to the specific pallet location and *viceversa*. PSs may be used in combination with both manually-driven forklift trucks and Laser Guided Vehicles (LGVs) providing material transport from the end-of-line area to the rack storage and from the rack storage to the loading area. The focus of this study is on the combined use of PSs and LGVs so as to discuss the design of a fully automated warehouse.

PSs help to overcome the disadvantages related to one of the most commonly used and space efficient type of racks storage, i.e. drive-in racks or similar solutions. Pallets stored in drive-in racks are not independently accessible so that all the levels of a certain lane must be devoted to the same item type and the amount of time to access the pallet locations increases as the lane depth and the number of levels increase. This may lead to efficiency losses. On the contrary, PSs allow different item types to be stored in independent levels of the same lane, so that an higher storage efficiency can be obtained even in long racks.

It should be pointed out that methods to support the design of a full automated logistics system are still in an early stage of development. In particular, to the authors' knowledge, studies about the joint design of LGV and PS fleets are not proposed in literature. Thus, this study aims to develop an analytical model for the integrated dimensioning of the fleet of PSs and the fleet of LGVs in a storage system.

Given a fleet of PSs acting as the server of the system, the proposed model provides the pallet shuttle utilization rate as a function of the number of LGVs, by taking into consideration the storage area layout and the production and delivery flows. The model identifies sets of feasible solutions, expressed in terms of number of LGVs and PSs, with the same PS utilization rate, i.e. that can be represented by iso-utilization contour lines. Finally, through the application of queuing theory results, the PS utilization rate of a certain set of solutions can be related to the expected cycle time (order release to shipment). The validity of the model is proved by discussing a real case study.

FACILITY LOCATION FOR INVENTORY REDUCTION: A PRACTICAL UPDATE ON P-MEDIAN HEURISTICS

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Determining the location of distribution centers is an important step in designing a supply chain network. The *p*-median problem has been extensively studied since early 1960's, in the effort of identifying *p*distribution centers to hold inventory amongst a network of *n* locations ($n \geq p \geq 1$).In spite its relevance, facility location is a managerial decision that is usually overlooked by many supply chain management education programs.Early works attempted to optimize the problem using algorithms – an attempt to reduce the computing time to solve the problem using mainframe computers – or heuristics, in an effort to find simple approximations that could be solved by hand and that provided results close to optimality.

This paper sheds light on this topic in a way that is valuable to today's practitioners, and recognizes past results that could have greater relevance todaythan at the time of their publication.We revisit "classic" p-median heuristics, updating them to be used with software and hardware easily available in most organizations today.We use demand requirements of F-16 spare engines in 33 bases of the US Air Force in 2008, and attempt to identify ideal inventory storage locations using several seminal heuristics. Actual constraints are introduced. A series of subjective and objective metrics are used to recommend the one heuristic that is easier to use, satisfies user's constraints and lowers inventory management cost.

The study has two important limitations: (1) the heuristics were not implemented literally as described by the original authors; when necessary, they were modified to incorporate some constraints not present in the original work, or to benefit from the design of existing software, without reduction of the heuristics' capabilities. Moreover, (2) as all heuristics, the results depend on the data used to test it. Other data might provide different performance.

The study contributes to the literature by exposing the need to review past results in Operations Management in light of computing capabilities available today. In this effort, it recommends an early heuristic that is simpler to use and provides better performance than what is obtained with other methods presented in textbooks.

Keywords: facility location, risk pooling, p-median problem, heuristic implementation, case study

A JOINT ECONOMIC LOT SIZE MODEL WITH RETURNABLE TRANSPORT ITEMS

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The literature on the joint optimization of order and production quantities typically considers a downstream flow of materials in the supply chain and tries to structure transportation processes between adjacent supply chain stages in such a way that a smooth flow of materials is achieved. Items that are transported in the opposite direction of the flow of finished products have only infrequently been considered. In many practical situations, however, products are transported on pallets or in containers, which may be reused after the final product has been delivered to the end customer. These so-called 'returnable transport items' (RTIs) have to be managed as well to assure that they are used economically and that investment costs are minimized. To derive insights for the management of RTIs, this paper develops a model of a supply chain that considers both the downstream flow of materials from the manufacturer to the buyer as well as the circulation of RTIs between both actors. The model is solved with the help of non-linear programming and a heuristic which is developed in the paper, and a simulation study is performed. The aim of the paper is to study how many RTIs should be installed, which shipment policy for materials and RTIs should be used from the manufacturer to the buyer, and how the RTIs should be returned form the buyer to the manufacturer. To the best of the authors' knowledge, this paper is the first to study the use of RTIs in a vendor-buyer supply chain.

Keywords: joint economic lot size model; returnable transport items; supply chain management; single vendor; single buyer

A NEWSVENDOR MODEL WITH DUAL SOURCING UNDER RISK AVERSION AND ORDER-DEPENDENT LEAD TIMES

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Dual sourcing is a common approach to reduceboth stocks and supply risks. By splitting replenishment orders among several suppliers, individual delivery quantities can be reduced at the expense of higher ordering and supplier handling costs. In addition, supply risks are reduced, as delivery problems at one supplier can be balanced by another supplier, at least in part. In addition, this will also result in reduced lead times and delayed order releases, which reduces uncertainty for the retailer.

One aspect that has not been considered in the literature is the fact that lead times are often dependent on order quantities in practice. Previous research has mainly focused on dual sourcing strategiesunder conditions wheresupply quantities or lead times are uncertain to some extent, but neglected the case where lead time is varying with the order size. The length of lead time, in turn, is important for the retailer as demand uncertainty usually increases the earlier an order has to be placed. In such a scenario, risks may be influenced by splitting replenishment ordersamongseveral suppliers and by thus reducing the length of the individual lead times, as well as by varying order quantities and replenishment policies.

This paper studies a single-product newsvendor model under demand uncertainty and considers the case where a retailer can source from two suppliers with different production technologies.The replenishment quantity is split among these suppliers, who initiate production upon receipt of the order and deliver the production quantity after the lead timehas elapsed.The retailer is assumed to be risk-averse and has to determine the optimal order quantities from both suppliers consideringthat these decisions will also affect the corresponding lead times and thus risks. Risk preferences of the retailer were included by using a mean variance approach.

The results of the paper indicate that dual sourcing strategies are beneficial for the retailer in certain cases, especially when the decision makeris highlyrisk-averse. In such a situation, building up redundancies in the supply chain is useful for hedging uncertainties that result from order-size-dependent procurement lead times. In contrast to a single sourcing approach, splitting orders between two suppliers also leads to larger order quantities when retail prices increase, which implies that risk effects will be overcompensated by the effects of dual sourcing in such a scenario.

Keywords: newsvendor model, dual sourcing, variable lead time, demand uncertainty, risk aversion

DETERMINANTS OF INPUT, WORK-IN-PROCESS AND OUTPUT INVENTORY LEVELS: AN INTERNATIONAL STUDY OF MANUFACTURING INDUSTRIES

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Objectives: Seen as a competitive weapon (Chikán, 2009) or a necessary pain, inventories are costly especially in downturn periods - like today's - when the access to the financial market is harder. In past, different solutions (e.g. just-in-time, vendor-managed inventory) have been proposed to reduce inventories, basically with the aim to push them away to other partners of the supply chain. However, the dynamics of inventories are quite complex. First of all, business cycles have impact on the level of sales and therefore on the overall level of inventories (McCarthy & Zakrajšek, 2007). Next, different types of inventories can be influenced by different variables. Work-in-process inventories are related to the type of process, e.g., production lines or job shops operate with different level of inventories. Finished goods inventories are related to the position of the decoupling point, e.g. to make-to-order or make-to-stock policies (Naylor, Naim, & Berry, 1999). Finally, raw material inventories are related to the uncertainty of supply and suppliers' lead time. However, literature does not provide a comprehensive framework that encompasses internal and external determinants of different inventory levels in manufacturing industries. By consequence, with this paper we try to fill this gap.

Materials and Methods: To analyze the problem we used data from the fifth edition of the International Manufacturing Strategy Survey. First we analyzed the trend of different types of inventories from 1991 to 2009 using data from 5 editions of the survey (one every 4-5 years). Next we focused on the last two editions of the survey with data collected in 2005 and 2009 – before and during the last crisis – to analyze the determinants of inventory levels. Given the international nature of the sample and the attention to contextual determinants, we integrated data from secondary sources (e.g. GPD per capita growth rate), as well.

Results: Results show that different types of inventories are impacted by different determinants. Finished goods inventories, are more dependent on external factors, namely the GDP growth rate and the position of the company in the supply chain. Consistently with some consolidated theories (bullwhip effect, Porter's competitive forces), the more upstream the company is, the higher its inventories are. For raw materials and work-in-process inventories, the picture is very different. These inventory levels are more dependent on internal factors (position of the decoupling point, investment in supply chain, product and process complexity). Finally, some determinants often advocated as significant by the literature, as the competitive priorities, demand uncertainty or the market dynamics do not seem to play a relevant role.

Conclusions: This study provides interesting insights in inventory management, integrating the economic and managerial perspective and shedding some light on the determinants but also the actions companies can undertake to reduce their inventories. In particular, specific strategies should be developed for the different types of inventories.

Keywords: operations management, inventory management, international studies, economic variables, IMSS

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RAIL CAR FLEET DESIGN: OPTIMIZATION OF STRUCTURE AND SIZE

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In the chemical industry, rail cars represent an important means of transportation. Due to safety regulations many products are not allowed to be transported on the road. Moreover, rail cars can carry larger volumes than trucks. The transported product poses certain minimum requirements on a rail car with respect to material, valve model, heating, etc. The combination of these characteristics specifies a certain rail car type and determines its cost. Types with higher quality characteristics can be used as substitutes for lower ones and thus are more flexible.

At the company, which motivated this research, the task of the fleet management team is to secure the supply with rail cars while at the same time optimally solve the trade-off between (i) minimizing the cost for rail cars and (ii) minimizing the number of different rail car types. A small set of different rail car types enables a parking strategy where the types are sorted by track. This keeps the handling easy. As the number grows, space limitations require a chaotic parking strategy. This causes an increase in the switching effort for providing a certain type. Further, the smaller the number of different types, the smaller the required safety stock due to a larger risk pooling effect. These benefits have to be traded off against the higher cost for more flexible rail car types.

We develop a mathematical model that provides the company with a suggestion of how to design the rail car fleet in terms of structure and size in order to solve the above mentioned trade-off. First, we use a MILP model that minimizes the total rail car cost under given availability constraints on the rail cars of a specific type. The switching effort reduction due to a smaller set of rail car types is hard to quantify in terms of cost.

Therefore, we do not directly include it as a cost term in the objective function, but consider the number of types as an additional constraint. Second, safety stocks are computed in an approximate way based on the rail car type-request assignment found by the MILP solution.

For this particular company setting, we observe a sharp cost drop when adding one additional rail car type to the minimal set, which is required for being able to satisfy all requests. A further extension of the rail car type set only leads to minor additional cost savings. These are easily outweighed by the increased switching effort. Therefore, we conclude that the best set of rail car types is the minimal one plus one.

Keywords: fleet management, fleet structure, fleet size, MILP, safety stock

RE-ENGINEERING INVENTORY MANAGEMENT PROCESSES AND PRACTICES IN A PUBLIC HEALTHCARE AND SOCIAL SERVICES ORGANIZATION

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Objectives of study: The main objective of the study is to re-engineer the inventory management processes in the South Karelia District of Social and Health Services (Eksote) in Finland. In South Karelia, a region situated in South-Eastern Finland, previously separate municipal health care and social services were integrated into a new organisation called Eksote in the beginning of 2010. Since then Eksote has arranged secondary health care, primary health care, care of the elderly, and social welfare services for its eight member municipalities with 130 000 inhabitants. Public healthcare is under an enormous cost pressure and thus Eksote needs to constantly increase its productivity and efficiency. Inventory management was identified as one of the main areas for development, and a study consisting of the following phases was conducted: (1) analysis of the current inventory management, ordering and demand forecasting processes, and inventory levels, (2) designing the to-be processes and setting the target inventory levels, (3) developing and implementing the tools needed, and (4) implementation of the re-engineered processes and tools in practice.

Materials and Methods: The main method is a case study done in the South Karelia District of Social and Health Services in Finland (Eksote) during 2011. Decision support tools aredeveloped and used to support the analysis phase and the actual implementation of the redesigned processes and practices.

Results: The outcome of the study is a unified process framework for managing inventory in a large public health care and social services organization. The study identifies the areas with the highest cost saving potential and sets targets for these areas. The study describes how decision support tools are used for implementing the new processes in practice. The study highlights the specific requirements and characteristics of the health care and social services sector in inventory management, and thus contributes to previous research done in this area.

Conclusions: The public health care and social services sector sets specific requirements to inventory management. As the cost pressures increase, public health care and social services organizations must review and re-engineer their inventory management processes and practices in order to increase their efficiency. The study proposes and describes a framework for re-engineering the inventory management processes and practices. Furthermore, the paper presents how decision support tools for planning and managing inventories in a public health care and social services organization are developed and implemented.

Keywords: public social and health care, inventory management, inventory management process, decision support systems, process re-engineering

OPTIMAL DYNAMIC PRICING AND ORDERING DECISIONS FOR PERISHABLE PRODUCTS

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In this paper, we determine the order quantity and the prices for a perishable product with a multiple period lifetime. Demands for products of different ages are dependent on the prices of mutually "substitutable" products. The problem for a product with lifetime of two periods is first analyzed and the stochastic dynamic programming model is developed. Given the inventory level for the old product (product of age 2), the expected profit is a concave function of the order quantity, the price of the new product (product of age 1) and the discounted price of the old product (product of age 2). The computational results show that the total profit significantly increases when demand transfers between products of different ages are considered. For a product with lifetime of longer than two periods, a heuristic based on the optimal solution for a single period problem is proposed for a multiple period problem.

Keywords: inventory; dynamic pricing, perishable product, demand transfer

SUPPLY CHAIN COORDINATION WITH STOCK-DEPENDENT DEMAND RATE AND CREDIT INCENTIVES

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The market competition significantly increases recently because of greater financial pressure, shorter product life cycle and varieties of competitive goods. Entities in the supply chain may be profited by sharing more information amongst them. Meanwhile, in real-life situations, the demand rate may be affected by the stock level. This occurs because high level of inventory receives more visibility; especially for certain perishable goods (e.g. vegetables, fruits and bread), high level of inventory may also imply that they are fresh and popular. However, few papers considered the cooperative mechanism between the manufacturer and the retailer when the consumption rate is stock-dependent. In this paper, we consider a supply chain which consists of a single manufacturer and a single retailer with a single product type. The consumption rate is assumed to be dependent on the retailer's stock level. First, without coordination, the retailer determines its order quantity to maximize its own profit, which is usually smaller than the manufacturer's economic production quantity. Then, under coordination, the manufacturer requires the retailer to increase its order quantity that the manufacturer can get higher profit. At the same time, the manufacturer should compensate the retailer for its lost profit and probably provide extra savings. We present three cooperative policies to coordinate the manufacturer's and the retailer's decisions. At first, the credit period policy and the quantity discount policy are developed and the total profits under the two policies are compared. Then we develop a centralized supply chain policy and show that it can achieve a perfect coordination. Under all three policies, we can prove that there are optimal order quantities to maximize both parties' profits. The centralized supply chain can always get more or equal channel profit, while it needs a close coordination and make decisions as an integrated company. If the centralized supply chain cannot be achieved, the credit period policy or the quantity discount policy is also a good choice. If the retailer's interest rate is higher than the manufacturer's, the credit period policy is better, otherwise the quantity discount policy is better. The manufacturer and the retailer can divide the surplus profit (compared with the no coordination case) by negotiation and the negotiation range will be given. Finally, some numerical examples are provided to illustrate the proposed policies.

Keywords: supply chain, stock-dependent demand, credit period, coordination, quantity discount

AN EXPLORATORY STUDY OF INVENTORY MANAGEMENT ISSUES IN A KIOSK NETWORK

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This paper investigates the inventory management problems of a unique network of approximately fifteen thousand small stores, called kiosks, dispersed in the Greek dominion. In a market hit heavily by recession, and in a sector where demand of customers is uncertain for a very large percentage of convenience products, multinational confectionery, food and beverage conglomerates, local product providers, wholesalers and retailers (kiosks) are dealing with the problem of out of stock situations that is greatly reducing profits of all parties involved. Meanwhile, the fact that, to a great extend, kiosks are a patent of Greece, makes it difficult for any manager to look up for a proper solution in the literature. As a result, a research in the sector proved to be necessary in order to fill the gaps in the literature, considering this sector of shops. The authors, therefore, have focused on finding the best appropriate inventory management policy on impulse demand products in Greece. Another objective of the paper is to identify the reasons and propose a solution to the immense problem of stock-outs that are widely met in the sector, focusing also on identifying the problems in the supplier (product provider) – wholesaler – retailer triangle in order to improve customer service levels. The methodology employed for the purposes of this study was an amalgamation of qualitative and quantitative methods. Questionnaires were distributed to kiosk owners and personal interviews were carried out with wholesalers at various cities in Northern Greece. The findings of the study revealed problems in all parts of the supply chain echelon, such as false forecasting on the companies' side (supplier), especially when it comes to new products, mistakes in the orders made by kiosks to wholesalers, and even indifference on the kiosk owners' side to keep a safety stock of their products. Based on the results, a number of conclusions were made. The fact that kiosks as shops have a limited capacity of keeping safety stock for the majority of products, combined with the indifference and unwillingness on the kiosk owners' side to keep such stock, necessitates the use of a stock monitoring system of kiosks by wholesalers in order to replenish the products before a stock out situation occurs. In addition, cash to cash cycle of kiosks is long due to the fact that all products are paid in cash that the buying ability of kiosk owners is minimized, causing the appearance of stock-outs.

Keywords: inventory management, kiosks network, impulse demand, convenience goods, cash to cash cycle

CASE STUDY: INVENTORY OPTIMIZATION USING ABC/XYZ MATRIX ANALYSIS FOR A FURNITURE RETAILER

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One of the largest expenses for distributors, wholesalers and retailers is stock. Many have difficulty finding the perfect balance between ensuring products are available when they're needed and not holding too much inventory. The critical situation on markets pushes companies to move from a supply-driven supply network to a demand-driven supply network. The benefits of such a move are obvious – lower inventories, reduced storage and handling costs, improved customer service and a more nimble supply chain that is able to commercialize and innovate at a faster pace. Optimization takes into account all dynamic variables that impact inventory levels. Through the use of these variables, and running them through algorithmic engines, an inventory profile can be achieved which will show an optimal balance between achieving the highest possible level of service with the lowest amount of network inventory. This article examines several multiple criteria ABC analysis procedures, ABC/XYZ matrix and a comparative study of their classification results is carried out on an example of a furniture retailer inventory system. This research is based on the data collected from the company's reports. The XYZ analysis is used to analyze the weighting of individual units according totheir consumption pattern. This means that a consumption fluctuation keyfigure is determined for each unit. Depending on how regularly a unit is consumed, it is assigned to one of the three classes, X, Y, or Z.The combination of ABC and XYZ analyses represents the ABC/XYZ matrix. Inthat matrix, there are combined the results of the two analyses and therebyobtain important information on inventories that enablesto define appropriate measures for optimizing the inventories. Results indicate that these different approaches produce statistically consistent rankings that help to improve inventory management for a furniture retailer the best way.

Keywords: inventory optimization, ABC/XYZ matrix, ABC analysis, XYZ analysis, inventory management

A FUZZY CROSS-EVALUATION APPROACH FOR MULTI CRITERIA ABC INVENTORY CLASSIFICATION

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Multi-criteria ABC inventory classification, which aims to classify inventory items by considering more than one criterion, is one of the most widely employed techniques for inventory control. For the multi-criteria classification, a data envelopment analysis (DEA)-like model, which generates a set of criterion weights for each inventory item and gives a normalized score to the item for a subsequent ABC analysis, have been proposed. DEA-like model determines weights exogenously and incorporates additional information from decision makers easily for inventory classification. However, the DEA-like model has three main limitations, which prevent effective inventory classification. First, many inventory items can share the same optimal score, which can hinder a precise classification of inventory items. Second, the model allows too much flexibility in weighting multiple criteria, and it can lead to an inaccurate classification of inventory items. Third, the model does not consider linguistic terms which come from decision maker's subjective judgments such as High, Medium and Low to assess each item under each criterion. To address these problems, we propose a fuzzy cross-evaluation method in DEA. Weemploy cross-efficiency evaluation in DEA to provide a finerinventory item classification and to applyfuzzy concept for measuringboth quantitative criteria and linguistic terms.We expectthat the proposed model can provide more reasonable and accurate classification of inventory items since it yields a unique ordering of the inventory items and eliminates unrealistic factor weights and considers measurable quantitative criteria as well as linguistic terms.

Keywords: ABC inventory classification, multi criteria analysis, data envelopment analysis, fuzzy concept

A SINGLE SUPPLIER-SINGLE BUYER BARGAINING MODEL WITH ASYMMETRIC INFORMATION AND PARTIAL VERTICAL INTEGRATION

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Most of the models on supply chain coordination assume either independent firms engaging in a supply chain relationship or a vertically integrated supply chain structure with a common ownership. Nonetheless, literature on management and organisation studies points to the emergence of partnerships which involve shared ownership between the business partners — and in particular such forms where one of the firms engaged in a supplier-buyer relationship owns a share in the other. Such supply chain forms can be described by the term *partial vertical integration*; to out best knowledge, they remained largely unaddressed by the supply chain research. This work is accordingly intended to introduce a model of the partial vertical integration based on the work of Sucky [A bargaining model with asymmetric information for a single supplier–single buyer problem, European Journal of Operational Research 171 (2006), 516-535] which is featuring the joint economic lot size modelling perspective and allows a single supplier to proactively design a menu of contracts for offering to a single buyer with an absolute bargaining power and a private information with regard to cost data. We extend both the Sucky's model and his optimality analysis to the case of the partial vertical integration by assuming that the buyer has a share in the supplier. A series of numerical experiments is conducted to capture the dependence of the supplier's bargaining surplus and optimal contract choice on the ownership share of the buyer in the supplier.

Keywords: supply chain coordination; joint economic lot size; asymmetric information; partial vertical integration

A ROBUST STOCHASTIC PROGRAMMING MODEL FOR A TRANSSHIPMENT ENABLED INVENTORY ROUTING PROBLEM

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In this study we develop a novel model for Transshipment enabled Inventory Routing Problem (TIRP) in a many-to-one supply chain. This chain is consisting of a plant fed by multiple suppliers spread geographically in entire the city. Each supplier is characterized by its own single product and a shared storage. There is also a capacitated fleet distributes products from the suppliers to the plant where the final product is assembled to response the customers' demand in a finite planning horizon.

In this many-to-one distribution network, a typical vehicle trip starts from the plant and continues by visiting several suppliers to pick up (or transship) the products and it ends by coming back to the plant and delivering the pickups. The proposed model considers transshipment to extend the possible solutions as well as the routs to enhance the performance of the supply chain; this way the trucks have this alternative to store pickups temporarily in the suppliers' storages to pick them up in the succeeding periods.

Shortage is not allowed. However, due to the uncertain nature of the demand, the inevitable shortages may occur in the pessimistic scenarios. So the risk-averse decision makers tend to plan according to the worse case. Consequently, the inventory related costs increase but the occurrence probability of shortage is decreased. On the other hand, the risk seeking decision makers tend to plan according to the best case. Therefore the inventory related costs decrease but the occurrence probability of shortage increases. To make a tradeoff between both conservatism and risky strategies a robust approach is applied to penalize the infeasibilities arise from the pessimistic scenarios.

The proposed model is a robust stochastic mixed integer programming and minimizing the weighted sum of the expected value of supply chain costs, infeasibility penalty cost and fleet overloading risk (i.e. the probability of not meeting the fleet size). The concept of overloading risk is defined here as the expected number of scenarios in which the number of vehicles (used in each period) is violated from a pre-specified fleet size. In other words, once the number of vehicles is planned to handle the transportation is violated from the fleet size, a significant extra charge is incurred to subcontract this part of transportation to the rental truck companies. Therefore the proposed model attempts to not only minimize the expected total cost of supply chain but also to make a tradeoff between the shortage penalty cost and subcontracting charges.

Uncertainty is presented by a set of discrete scenarios forecasting the possible future demands. Each scenario is associated with a probability level representing the decision makers' expectation of the occurrence of that scenario. In this study four scenarios are generated for four possible states; poor, fair, good and bloom with occurrence probability of 0.25 for each one. Some numerical examples are solved to demonstrate the validity and applicability of the proposed model. Also a sensitivity analysis is done for the relative weight of objective function components.

$$Min\ Z = \lambda \times E[total\ cost] + \omega \times (overloading\ risk) + \theta \times (infeasibility)$$

Keywords: robust stochastic optimization; inventory routing problem; transshipment; uncertainty; fleet overloading risk

BOTH PARETO AND EOQ HAVE LIMITATIONS COMBINING THEM DELIVERS A POWERFUL MANAGEMENT TOOL FOR MRP AND BEYOND

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The author's research has shown that 50% of ERP systems MRP modules do not provide parameter setting tools for optimizing the cycle stock settings, mostly offering Fixed Order Quantity and Fixed Period which require the User (Planner) to determine and manage the settings. It also identified that where the tools, like EOQ, were provided that the User does not use them preferring to use their judgment instead.

Pareto and EOQ are the most readily available tools used for the setting of cycle stock and management of inventory in the majority MRP systems. The paper critical examines these two techniques and identifies their strengths and weaknesses. EOQ is often challenged and many alternatives have been developed in an attempt to overcome the weaknesses. Whereas Pareto is not so widely challenged and is widely used as a rough guide for inventory planning

Firstly a closer look at Pareto, through the evaluation of MRP data from manufacturing businesses the paper shows how Pareto can produce a less than optimum result and identifies the root cause of the weaknesses. Thus it can be shown that Pareto's strength only applies when a whole group of parts are evaluated; any division into a sub-set and the risk of a sub-optimal answer is increased..

Second a critical examination of EOQ and its more popular derivatives summarises the arguments that are well documented and debate the validity of the basic premise that is contained in the cost of inventory and the cost of ordering. The key weakness is that often the data required for accurate evaluation of EOQ is not typically available in most businesses.

Finally the paper examines an alternate technique the k-curve, first identified in the 1990's, which is derived by combining the two techniques of Pareto and EOQ and shows how it successfully eliminates the weaknesses and enhances the strengths of Pareto and EOQ. There is a increasing body of academic evidence that demonstrates the robustness of K-curve as a solution to the weaknesses of Pareto and EOQ.

The paper uses material gathered from manufacturing businesses in recent years and shows how the k-curve methodology has been successfully applied as a business management tool and can then be used to determine the optimum parameters settings for individual items within an MRP environment.

The paper concludes by demonstrating that the use of k-curve as a MRP management tool is a significant advance since the effective management of MRP parameters is simplified to a easily made business judgement.

Keywords: inventory, business systems, MRP, manufacturing requirements planning, cycle stock, K curve, EOQ, Pareto, process improvement

SIMULATION OPTIMIZATION FOR THE STOCHASTIC ECONOMIC LOT SCHEDULING PROBLEM WITH SEQUENCE-DEPENDENT SETUP TIMES

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We consider the stochastic economic lot scheduling problem (SELSP) with lost sales under compound Poisson demand, where switching between products is subject to sequence-dependent setup times. The objective is to find a sequencing and lot-sizing policy that minimizes the expected average cost over an infinite planning horizon.

We model the problem as a semi-Markov decision process (SMDP). Decisions involve continuing production of the same product, switching to another product, or going idle.

Since the problem cannot be solved in closed form and the dynamic program is too complex, we propose a solution based on simulation optimization and investigate its performance numerically. Simulation optimization for the SELSP has already been studied in Löhndorf and Minner (2012) but only for sequence-independent setups.

Our approach is based on an iterative two-step procedure which combines direct policy search with heuristics for the traveling salesman problem. The first step involves setting order-up-to-levels and production frequencies for each product. The second step involves finding an optimal production cycle for the given frequencies. Order-up-to levels and production cycle then define a production control policy which can be simulated to compute the expected average cost.

To find an optimal production cycle, we compare three different approaches. The first approach is to minimize the cycle time of the common cycle. The second approach is to minimize the cycle time of a cycle where products are built according to their frequencies. This allows high-volume products to be produced more frequently than low-volume products. For both approaches, we resort to the Lin-Kernighan heuristic to minimize the cycle times. The third approach is to minimize the cycle time of a balanced cycle, which additionally requires that the expected interarrival times between setups of the same product are balanced. For this approach, we propose a modified version of the k-opt heuristic to find a balanced cycle with minimum cycle time.

Based on a large-scale numerical study, we find that for instances with 10 or more products, a policy with a balanced production cycle outperforms a policy with an unbalanced cycle, which indicates that merely minimizing the cycle time of a production cycle is often insufficient. For asymmetric model setups, production cycles, which allow some products to be produced more frequently, outperform production cycles, where each product is produced only once.

Keywords: production scheduling, lot-sizing, stochastic demand, sequence-dependent setups, simulation optimization.

A SIMPLE HEURISTIC FOR VEHICLE ROUTING AND KEEPING LOW TRANSPORT INVENTORIES – A VARIANT OF CLARKE AND WRIGHT'S SAVING METHOD

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A variant of the Clark and Wright's saving method is presented. Only the first calculated pairs of saving are used, also when complements or additions are searched for an already decided route. The variant is simple, very fast and it shows good and satisfactory results. (It finds the best know solution to the Danzig and Ramser (1959)–problem) Therefore it is suitable for the introduction of the topic and importance of efficient vehicle routing. Efficient distributions and collections are important because they use less recourses and energy; it makes the world more sustainable. A lot of goods are always under transport; efficient distributions to retailers, customers etc and collections from storage racks, different depots etc decrease transport inventories.

Keywords: vehicle routing, transport, scheduling, heuristics

COURTS OF JUSTICE AS A PRODUCTION-INVENTORY SYSTEM

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A persistent delay problem existing in the justice court processes has led to a growing pressure to improve the process performance in different court instances around the world. This pressure has led to a rise in the use and application of different techniques of process performance improvement traditionally designed for the manufacturing industry, with varying results. Consequently, as a basis for implementing successful process improvement solutions, the special characteristics of the "legal case production" need to be thoroughly analyzed and understood.

The objective of the paper is to identify and analyze the most important production scheduling and work-in-process control challenges existing in justice court processes. The aim is also to analyze the primary causes behind the challenges and to describe possible solutions to improve the scheduling, priority management and work-in-process control.

The research is a multiple-case study based on five longitudinal action research projects carried out in five different Finnish Courts of Justice. The courts operate in different roles in the Finnish legal sector and have differences in their product range and process structure, providing a good cross-section and overview to the challenges inherent in court production and operations. The study utilizes diversified data collection methods: semi-structured interviews, participant observation and field notes from process improvement workshops, as well as statistical data.

The findings of the paper indicate that the product variation in the sense of size and urgency of the cases has the highest impact on the challenges and needs of production planning and work-in-process control. Product variation causes especially two types of challenges: difficulties in capacity and resource management and problems in priority management.

The paper uses a product range categorization framework to analyze the nature and level of production control challenges inherent in the process. The paper introduces production scheduling and work-in-process control methods for different types of product range situations. The paper also discusses the operability and feasibility of the designed methods.

Keywords: courts of justice, process improvement, production planning, work-in-process control, product variation

SUPPLY DIVERSIFICATION WITH RESPONSIVE PRICING

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We study sourcing and pricing decisions of a firm with correlated suppliers and a price-dependent demand. With two suppliers, the insight---*cost is the order qualifier while reliability is the order winner*---derived in the literature for the case of exogenously determined price and independent suppliers, continues to hold when the suppliers' capacities are correlated. Moreover, a firm orders only from one supplier if the effective purchase cost from him, which includes the imputed cost of his unreliability, is lower than the wholesale price charged by his rival. Otherwise, the firm orders from both. Furthermore, the firm's diversification decision does not depend on the correlation between the two suppliers' random capacities. However, its order quantities do depend on the capacity correlation, and, if the firm's objective function is unimodal, the total order quantity decreases as the capacity correlation increases in the sense of the supermodular order. With more than two suppliers, the insight no longer holds. That is, when ordering from two or more suppliers, one is the lowest-cost supplier and the others are not selected on the basis of their costs. We conclude the paper by developing a solution algorithm for the firm's optimal diversification problem.

Keywords: supply diversification, responsive pricing

A NEW ALGORITHM FOR LOST-SALES INVENTORY CONTROL

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This paper proposes a new approach, based on approximate dynamic programming, for the classic lost-sales inventory problem in discrete time with stochastic demand and a positive lead time. The approach exploits recent results about the structure of the exact optimal-cost function, namely, that this function has a property called L♮-convexity. We approximate the exact function by a linear combination of simple functions with the same property. To find a good approximation, we sample the state space by generating trajectories in a systematic way. The end result is a fairly simple heuristic policy, somewhat like a base-stock policy, but using a weighted sum of the outstanding orders instead of the standard inventory position. Numerical tests indicate that this policy performs quite well.

THE ROLE OF SUPPLY CHAIN INTEGRATION IN INCREASING THE "SNOWBALL EFFECT" IN THE TRANSMISSION OF DISRUPTIONS

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Supply chains are now more than ever susceptible to many diverse risk factors and their negative consequences, often referred to as disruptions. Such disruptions may be propagated and amplified alongside a supply chain, which constitutes the phenomenon of the "snowball effect". It is important to identify and estimate the "snowball effect" as it may have a substantially disruptive impact on supply chains.

The major source of the "snowball effect" in the transmission of disruptions are close and integrated relationships between supply chain partners. This is a very striking observation, as integration determines the supply chain efficiency, and is often depicted as the essence or pillar of the concept. However, integration may also lead to an excessive mutual dependence of companies in a supply chain. Consequently, over-dependence may cause amplification and propagation of disruptions in part of or in the whole supply chain.

The paper explores the relationships between the level of inter-organizational integration and the amplification of disruptions propagated alongside a supply chain. The hypothesis is that more intense integration between companies promotes higher strength of the "snowball effect" in the transmission of disruptions in supply chains.

A survey of companies has been conducted and statistical analysis has been performed in order to address the hypothesis. Having conducted Principal Component Analysis (PCA), the constructs reflecting an intensity of integration between companies in supply chains were extracted. They were then employed as classification criteria in a cluster analysis. The results of the study show that the examined companies can be grouped into classes with a distinct strength of the "snowball effect" in the transmission of disruptions.

Keywords: propagation, amplification of disruptions, risk, collaboration, supply chain

SOLVING THE DISASSEMBLE-TO-ORDER PROBLEM UNDER YIELD PROCESS MISSPECIFICATION

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Remanufacturing of returned products is an environmentally friendly as well as a very cost-efficient way to satisfy the amount of "as good as new" products, which tends to increase rapidly in the next years. Since the returned products differ with regard to quality, a random yield problem results in which one is never sure how many good quality parts will be harvested from the disassembly of a certain returned product. The disassemble to order (*DTO*) problem concerns itself with how many of each re-turned product to disassemble in order to meet a specific demand of different parts of the product. Approaches to incorporate random yields into *DTO* problems assume two types of yield randomness. The first approach, proportional random yields (*SP*), presumes that the yield rate parameters do not change by increasing or decreasing the number of products to disassemble. Another yield modeling approach, binomial random yields (*BI*), does not require this assumption but is considerably more com-plex to analyze (see [1] and [2]).

Until now, there has been absolutely no attention paid in the literature on which of these two approaches might prevail in practice. Using actual yield data from a car engine remanufacturer, we have tested if one of the modeling approaches is better fitting concerning these data. To test for *BI* yield we used a $\chi 2$*-Test* to check if the yield data might come from a binomial distribution with an expected success proba-bility p. We then tested for statistically significant differences in variances between small lots and large lots by using a *Brown-Forsythe-Test*. From the results we can conclude that none of the yield modeling approaches mentioned above can be used alone throughout all parts of the engine to represent the outcome of the disassembly process.

Our contribution also aims at exploring the sensitivity of *DTO* decisions to misspecifi-cation of the random yield modeling approach. In order to examine the impact of us-ing the wrong modeling approach in decision support, we present a study based on the product structure used in [3]. For this product structure, the optimal decisions can be obtained both for *SP* and *BI* yields. With these decisions on hand, we can calcu-late the performance loss to a misspecification of the yield model as a relative cost deviation and we are able to indentify cases in which a misspecification of the yield type has a strong impact on the cost performance.

Keywords: remanufacturing, disassembly, random yields, yield process misspecification

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MANAGING CORES FOR REMANUFACTURING DURING THE PRODUCT LIFE-CYCLE

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For remanufacturers, collecting cores is critical for the success of business. Withoutenough cores, remanufacturing production lacks the raw materials and its process needs to be stopped. This leads to lost sales in the market, or alternatively it creates extra costs due to the acquisition of virgin materials. On the other hand, with too many return cores, there will beobsolete risk of holding such items. Therefore there is aneed to manage appropriate amount of cores by collecting and disposing them. When we consider the product life-cycle perspective, the above issue becomes even more vital. The availability of cores is changing along with time, and its cost of collecting varies as well. For example, at the earlier stage of the product life-cycle, coresare rare and expensive, since few products are returned due to parts failure or being disposed;in the later stage there will be more cores available from repaired parts or retired products,thus the price of cores may drop quickly. In addition, the demand of remanufacturedproducts is alsoquite different along the life-cycle, which makes the decision of core acquisition more complicated.

Based on the above observation from industry, this paper applies firstthe diffusion model to describethe dynamics of core availability, demand of remanufactured products, and core priceduring the product life-cycle. We investigatehow the factors such as parts failure rate, products retirement rate, affect the interaction of new product sales, return of cores, demand of remanufacturing parts. In order to maximize the profit of the remanufacturer over the entire life-cycle, optimal control theory is usedto determine how to manage return coresat different stages of product life-cycle. Besides, several heuristic strategies of core collecting will be tested to obtain practical management insights.

Keywords: remanufacturing, core collecting, life-cycle, optimal control, core price

INVENTORY POLICIES FOR AMELIORATING ITEMS

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Objectives of study: Most of the inventory models developed in the literature deal with items that preserve their value while they are stored in the warehouse or, at least, deteriorate over time. In this paper we will deal with a special class of items, known as "ameliorating items". Such items hold the relevant characteristic of increasing their value over time, particularly while they are stored. Some of the main examples which inspired the contribution belong to food production and supply, as in the case of aged cheese (e.g. the well known Parmigiano Reggiano or Grana Padano) or red wines, that acquire value over time once bottled. However, other types of products characterised by "ameliorating" processes have been already identified. It should be mentioned that few literature exists concerning inventory decision for this special class of items (the first paper that addressed this topic is Hwang, 1997).

The aim of this study is to present a class of policies for ameliorating items, under different hypotheses that are realistic when compared to the products considered. The contribution discusses a specific function of time for the aging of products in the warehouse; moreover, the demand will be considered as a function of the value of the items. Finally, the practical case of a limited warehouse, where the items can be stored, will be addressed.

Materials and Methods: We will introduce a mathematical model, the objective function of which is represented by the profit maximisation of the single actor considered. The actor sells the items at a price depending on the aging period and at a rate depending on it, the costs faced are the set-up cost (for producing the items and locating them into the warehouse) and holding costs keeping the items stored (often, the items of this kind require specific environmental conditions for a successful aging).

Results: Numerical analysis applied to a specific case and real data will be offered so as to show the applicability of the model to practical cases.

Conclusions: The main findings of this work are represented by the model developed, that may be helpful for mangers involved in decision making for items gaining value over time, i.e. while they are stored. More general managerial issues will be based on the numerical applications of the model to data available from real contexts.

Keywords: ameliorating items, price dependent demand, limited capacity warehouse

Mathematical Models of Inventories

OPTIMAL REPLENISHMENT SCHEDULE FOR FINITE HORIZON MODELS

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In 2009 Benkherouf and Gilding presented a general methodology for finding an optimal replenishment schedule for a class of single item economic lot-size inventory models. The search for an optimal schedule was formulated as a mixed-integer non-linear program. And in order to apply the methodology it was required that the objective function of the mixed non-linear program be in a certain format and to pass a couple of technical tests. In turns out that a large class of inventory models (which seems unrelated) can be put in the format required by the methodology and consequently a unified approach for finding the optimal inventory policy can be applied to them. This paper will review the methodology. Illustration of the methodology with a simple example is also presented. Furthermore, potential applications of the methodology to several inventory models will be discussed briefly. Of particular interest models for

1. Optimal batching for a production-inventory model: see Rau and Ou Yang (2007).
2. Joint remanufacturing a manufacturing as discussed in Konstantaras and Skouri (2008).
3. Lot sizing for recoverable product with inspection and sorting: see Konstantaras and Skouri and Jaber (2010).
4. Optimal integrated-policies for a vendor-buyer model: see Benkherouf and Omar (2010).

Keywords: inventory lot-sizing, remanufacturing, finite horizon models, inspection, optimization

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ON THE EQUIVALENCE OF INVENTORY MODELS BASED ON CLASSIC AND NET PRESENT VALUE PRINCIPLES

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It is generally accepted that inventory theory should be able to account for the time value of money. This foundation goes back to Harris (1913), who was careful to explain that the unit holding cost in his EOQ model captures the opportunity cost of capital. The opportunity cost is also the foundation for the Net Present Value (NPV), which is the Laplace transform of a cash-flow function (Grübbstrom, 1967). It is known at least since Hadley and Whitin (1963) that the EOQ model returns solutions close to optimal from the NPV perspective under certain conditions. Since Grübbstrom (1980), it is known that the equivalence of classic models (average costs and infinite horizon)and NPV models based on linear approximations of annuity stream functions is contingent on assumptions about the cash-flow function. We formalise the notions of equivalence, perfect equivalence, and non-equivalence, using concepts from set theory, and provide examples of models where equivalence is established. This is then re-assuring, as it validates the use of the classic model within the cash-flow assumptions of the equivalent (class of) NPV models. Even if a classic model shows equivalence with some NPV models, it is certainly possible that the context in which it has been used leads to non-equivalence. We present some examples. Finally, we present some classic inventory models for which we can show non-equivalence under a wide variety of plausible cash-flow functions, with solutions that differ significantly, and for which we have yet not been able to establish equivalence when the time value of money is important. It cannot be established that this implies non-equivalence in general to any NPV model, but it does cast some doubt on the validity of the classic model and the inventory policies it suggests.

Keywords: average cost; net present value; EOQ models; set theory; optimisation

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PERFORMANCE OF THE CLARK-SCARF ALGORITHM IN MULTI-ECHELON INVENTORY SYSTEMS WITH LOST SALES

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We study the problem of managing a serial inventory system under periodic review when excess demand at the most downstream stage is lost. In multi-echelon, retail supply chains, the assumption that excess downstream demand is lost is more meaningful than the assumption of backordering. Demands are stationary and stochastic. We are interested in minimizing the long run average sum of holding and penalty costs incurred per period.

If excess demand were completely backordered, it is optimal to have all locations follow echelon order-up-to policies (policies that raise the total inventory in every echelon to a certain echelon-specific target level). However, when excess demand is lost, even the optimal policy for a single location problem is not of such a simple form. Therefore, it is clear that the optimal policy for the multi-echelon problem with lost sales will not be simple either. We answer the following question: Under what conditions is the class of echelon order-up-to policies close to optimal?

We consider the echelon order-up-to policies suggested by the algorithm of Clark and Scarf. When we use this algorithm for lost-sales models, we must specify the backorder cost parameter. First, we prove that when this parameter is chosen to be equal to the lost-sales cost parameter in our model, the resulting policy is asymptotically optimal as the penalty cost grows large. Secondly, we generalize this asymptotic optimality result when the backorder cost parameter is an increasing function of the lost-sales cost parameter whose slope is bounded below and above by strictly positive constants.

Our theoretical results open up two interesting questions which we also study: (a) How cost-effective is the best echelon order-up-to policy at moderate penalty costs? (b) Given that there is a large family of asymptotically optimal echelon base-stock policies, how can we pick one which offers good performance across a wide range of problem parameters? To answer the latter question, we fit a power series with regression analysis on the best choice of the backorder cost parameter input as a function of the lost-sales cost parameter. The numerical experiments show that the policy computed using the approximation leads to a cost increase of less than 1% relative to the best order-up-to policy, whereas the best echelon order-up-to policies provide excellent cost performance with an average gap of 1.6% relative to the costs of the optimal policies.

Keywords: multi-echelon, lost sales, optimal policy, order-up-to policy

ENERGY FOR STABILISATION OF PERISHABLE GOODS IN COLD LOGISTIC CHAIN

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We consider that production and logistics facilities in the supply chain are positioned between the origin and the supply market or in a part of it. Energy is needed for cooling, which influence added value of the activities. In L4L systems some distances between the production or distribution node and their child node are much longer than other, which additionally influence appropriate timing. Any changes in time-distance or temperature in the chain could cause the net present value of the activities and their added value in the supply chain to be perturbed. The perturbations can be robust. The natural question arises is to what are the effects of some perturbations in a supply chain, in its production or distribution part, on the stability of perishable goods in such systems and what is the appropriate control which keeps the product on the required level of quality and quantity at the final delivery, if the cost of energy is not negligible. These analyses are especially important to assure the stability of cold chains in the cold chains management (CCM) at affordable costs of energy. What conditions should be fulfilled to assure, that after such robust perturbations of parameters the behaviour of the logistics chain would still be within the prescribed limits.

The formulation obtained in the time domain will be compared with the formulation in the frequency space introduced by Grubbström in his paper "On the Application of the Laplace Transform to Certain Economic Problems" (Manage. Sci. (7) (1967) 558). Also, for the needs of this article, his basic approach to MRP is extended so that also transportation delay play important role and can not be just added to the production delay in the nodes, described by the diagonal matrix of delays. In the paper of Bogataj and Grubbström: "Transportation delays in reverse logistics" (Int. j. prod. econ. (2012), doi: 10.1016/j.ijpe.2011.12.007.) this approach is explained in details. The energy is added to the consideration in fundamental equations in extended MRP theory (EMRP) which influence added value of cold chains and, therefore also net present value (NPV) of all activities.

Keywords: logistics; lead time; energy; laplace transforms; MRP; robust perturbations; cold chains; cold chains management; perishable goods

AN ORDER FULFILLMENT MODEL WITH A PERIODIC ALLOCATION REVIEW MECHANISM IN FOUNDRY FABS

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In today's globalization competition, manufacturing firms are using an order fulfillment system to give available-to-promise (ATP) capacity efficiently. An ordinary order fulfillment system will plan capacity based on forecasts and assign ATP quotas to incoming orders. Its basic idea is to enhance capacity utilization and customer service. However, in the semiconductor industry, demand is highly volatile, and a make-to-order (MTO) manufacturer often runs the risk of cancelled committed demands. In this research, we propose an integrated order fulfillment model for a MTO foundry fab to maximize corporate profit. Specifically, we suggest a periodic allocation review mechanism to reallocate unused ATP quotas. We examine the model performance based on different data sets. Results showed that capacity utilization and profitability are improved substantially with the periodic review mechanism, especially when demand forecasts are not reliable.

Keywords: available-to-promise, make-to-order, periodic review, order fulfillment, foundry fab

CUSTOMER WAITING TIMES IN (nQ,R) INVENTORY SYSTEMS WITH COMPOUND POISSON DEMAND

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Customer waiting time is a critical variable in heuristic modeling of multi-echelon inventory systems. It is not sufficiently investigated in the literature, which is large.

The paper reviews and comments the literature and extends it by investigating customer waiting times in(nQ,R) inventory systems with continuous review and compound Poisson demand and with R+1<0 allowed. Two basic cases are considered: the waiting time for an average unit of demand assuming partial deliveries, and the waiting time for a customer demanding *d* unitswhen only full deliveries are allowed.

The probability distributions are characterized and exact and approximate formulae are derived for means and variances.There are some computational results of various heuristics for the mean and variance of waiting time in each of the cases.

Keywords: inventory control, (nQ,R)policies, customer waiting time, compound Poisson demand, inventory theory

LEAD-TIME INVESTIGATION AND ESTIMATION

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It is well known that longer and more uncertain lead-times in a distribution system increase the need for safety stock and/or reduce the service level at lower levels. It is also well known that ordering decisions at higher level of the supply chain have an impact on the lead-time. Yet not much research has been devoted to increasing the knowledge of how exactly these decisions do influence the lead-time and there is a lack of simple methods to estimate the expected value and variance of the lead-time. Recent research that strongly indicates that it is optimal to provide a low service level at the earlier stages only emphasizes the importance of shedding a light on this issue. This as lower service levels leads to prolonged and more frequent stock outs and hence longer and more uncertain lead-time

In this paper we provide a large simulation study of a two-level distribution system where different decision parameters as well as external parameters influence the lead-time are investigated. Not surprisingly, the study shows that the service level at a higher, not surprisingly, has a positive effect on both the length and variability of the lead time, i.e. they decrease with an increasing service-level. More interestingly though, is that of the other parameters it is only the order quantities that has a significant impact on the lead-time. Both the expected value and variance of the lead-time increase with the retailer's as well as the central warehouse's order quantity. This can be describe as an inverted bullwhip effect as the lead-time variability increase as one moves down the supply chain towards the end customer.

In the paper we also develop simple methods to estimate the mean value and variance of the lead-time. The methods are based on replacing a stochastic lead-time demand at the central warehouse with a stochastic demand rate. For a given inventory position and demand rate it is shown how to compute the delay at the central warehouse due to stock-outs in a straight forward manner. These delays are then weighted together based on the probability for each combination of inventory position and demand rate to attain the estimates. The difference between the developed methods lay in how the stochastic demand rate is estimated. The above mentioned simulation study shows that the estimates exhibit a good accuracy and constitutes an improvement compared to existing methods with similar computational complexity.

Keywords: distribution system, stochastic demand, lead-time, estimation, simulation

COORDINATION OF SUPPLY CHAINS UNDER BUDGET CONSTRAINTS

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Budget constraints and capital costsare commonly considered in real decision frameworks; however, the supply chain contract literature has not addressed the contract design for supply chains with budget-constrained members who consider capital costs. To show the impact of budget constraints, we demonstrate that some optimal decision rules with risk-averse members are no longer optimal when we consider the budget constraints. Based on this, we study how the revenue-sharing (RS) contract and buy-back (BB) contract work in the supply chain coordination under budget constraints and obtained some interesting findings. Given an order quantity, the members under the RS contract can increase the upper bound of their profits by increasing their own budgets; however, under the BB contract, larger budgets cannot increase the upper bound of their own profits. If the member wants to increase the upper bound of his own profit, he needs to negotiate with the other member to increase that member's budget. It means that the BB contract might be unfair to both of the members, especially to the retailer. This unfairness might be larger when the retail price is high. Based on this, we propose a new contract which can resolve this problem. We point out two basic requirements for the composite contracts that are helpful to the managers. Then, we propose a revenue-sharing-and-buy-back (RB) contract that combines two subcontracts: a revenue-sharing (RS) contract and a buy-back (BB) contract. Next, we discuss how the RS, BB, and RB contracts work to coordinate a two-stage supply chain with budget-constrained members who consider capital costs. It is shown that the RS and BB contracts are not feasible under certain budget scenarios, while the RB contract can always coordinate the supply chain and arbitrarily allocate the total supply chain profit. The advantages of our RB contract are twofold (i) The RB contract can lead larger total profit and flexibility in terms of profit allocation under certain decision frameworks; (ii) the administrative cost of the RS or BB contracts can support the RS contract. Our analytical and numerical results lend insights into how the managers select an appropriate contract based on their budget scenario.

Keywords: revenue sharing, buyback, supply chain, budget constraints, capital costs

CUMULATIVE STAIRCASE CONSIDERATIONS FOR DYNAMIC LOT SIZING WHEN BACKLOGGING AND/OR LOST SALES IS ALLOWED

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The *dynamic lotsizing problem* concerns the determination of optimal batch quantities, when given required amounts appear at different discrete points in time. The standard formulation assumes that no shortages are allowed.

Assuming no shortages permitted, previously it has been demonstrated that the *inner-corner condition* for an optimal production plan in continuous time reduces the number of possible replenishment times to a finite set of given points at which either a replenishment is made, or not. The problem is thus turned into choosing from a set of zero/one decisions with 2^{n-1} alternatives, of which at least one solution must be optimal, where n is the number of requirement events. This condition applies, whether an Average Cost approach or the Net Present Value principle is applied, and the condition is valid in continuous as well as in discrete time problems.

In this paper we investigate consequences for the inner-corner condition, when backlogging and/or lost sales are allowed.

Keywords: dynamic lotsizing, backlog, lost sales, net present value, economic order quantity, EOQ, binary approach

OPTIMAL ISSUANCE AND DEPLETION OF PERISHABLE PRODUCTS UNDER A PERIODIC ORDER-UP-TO *S* POLICY

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Objective: The management of inventories of perishable products with a short maximal shelf life takes a good issuing policy next to a good ordering policy. Order policies of non-perishables are well studied in literature and implemented in Automated Store Ordering (ASO) systems and Computer Assisted Ordering (CAO) systems. These order policies are stock-level dependent and do not take stock age into account. As a consequence when applied to perishable products they do not anticipate expected future outdating of products and thus result in unnecessary outdating and shortages. In this paper we investigate whether a clever issuance policy helps improving the performance of inventory systems of perishables with a short fixed shelf life.

Materials and Methods: We present a stochastic model to determine which products to issue to meet the demand that is solved by stochastic dynamic programming (SDP) in case replenishments happen by an order-up-to *S* policy. The SDP model allows formulating preferences for specific age categories.

Results: From a simulation study for slow moving perishables it appears that the optimal issuance policy improves the quality of service in two ways: 1. it aims at issuing fresher products, 2. it reduces shortages by implicitly planning future outdating. The insight obtained from the optimal issuance model triggered us to study optimal depletion policies that may have a similar effect but are simpler to implement in practice.

Conclusions: The performance of inventory systems may be improved without considering complex stock age dependent ordering policies. Via the computation of a complex issuance policy we show that a simple depletion policy may do quite well.

Keywords: perishable inventory management, dynamic programming, simulation, issuance policy, depletion policy

HUB-AND-SPOKE SHIPPING APPROACH TO THE ICGCPS

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The international cooperative global complementary production system (ICGCPS) is a global production system with several local production bases located in a number of countries. Each production base requires component parts from the bases in all the other participating countries. Moreover it assembles different type final products, so that in order to supply them to the domestic market as well as the overseas market. This paper aims to improve the performance measures of the ICGCPS of the automobile manufacturers such as the inventory level at the depot and local production bases and the total transportation lead time as well as the average rate of loading during the transportation process. We introduce a transportation method so called mixed-loading transshipment method that is a kind of hub-and-spoke shipping model. We formulate a car carrier ship routing problem that minimizes the total transportation lead time and the sum of transport vessels required in the form of a mathematical programming problem under the following assumptions; (1) each production base produces some final products for the total demand required in all the participating countries and the overseas market, (2) we can transship the final products only at the depot. Some numerical examples will be shown in order to clarify the effectiveness of the transportation method proposed.

Keywords: production, inventory and transportation problem, international cooperative global complementary production system, mixed-loading transshipment method

STEADY STATE ANALYSIS OF LINEAR CONTROL RULES IN RANDOM YIELD PROBLEMS

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It is well known that inventory control rules become highly complex if production systems are characterized by yield randomness. Research contributions from Bollapragada/Morton (1999) and Huh/Nagarajan (2010), however, reveal that under a critical stock policy linear control rules perform very well in the case of zero lead times. An extended approach by Inderfurth (2009) that also incorporates non-zero production lead times only offers heuristic procedures for parameter determination of a linear control rule. How to optimize control parameters in this case is still an open question.

In this contribution it is shown how a steady-state analysis can be used to develop closed-form expressions of the moments of the system variables. To this end the stochastic process of time-development of the inventory and production variable is modelled under a linear control rule and random yield, and it is analyzed how these variables behave if the time horizon goes to infinity. Through this analysis it becomes visible how the expected value and variance of production quantity and inventory level depend on the mean and variance of the yield rate as well as on the length of the production lead time. Especially, one can observe how the variance of inventory and production increases with growing coefficient of variation of the yield rate and with rising lead time.

The knowledge of the mean and variance of the inventory and production variable can be used to formulate a cost function that describes in closed form how the expected inventory holding and backorder costs depend on the parameters of the linear inventory control rule. It is shown how under the assumption of normally distributed inventory variables this cost function can be exploited for parameter optimization. Thus, also in the general non-zero lead time case an approach for determining optimal or near-optimal control parameters in an environment with random yield is given.

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THE AIRLINE YIELD MANAGEMENT WITH EARLY DISCOUNT SETTING

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Coping with the high competition among other airline companies, an airline company takes efforts to capture as many as customers as early as possible. Recently web reservation system become popular and so we onsider a model of flight ticket reservation with early discount setting as follows:

(1) Ticket of economy seat on a flight at a certain day is considered.

(2) There are two price setting, that is, early discount ticket with price r_1 and that of regular price r_2 $(r_1 \le r_2)$. Customer can buy the former ticket on line by internet during the certain period before the flight time, for example, 60 days before and after that, only regular price ticket is available. But this paper assumes that some customers overflowed from the limited seat number $S (< T$: total number of economy seat) buy the regular price ticket and this percent of transfer to regular seats is *P*.

(3) Cumulative distribution of early discount ticket demand D_1 is F_1 and that of regular ticket demand D_2 F_2 and density distributions of those demands f_1, f_2.
Further we assume that $F_1(0) = f_1(0) = 0, F_2(0) = f_2(0) = 0$.

(4) Under the above setting, *S* maximizing the expected profit should be sought.

First we calculate the expected numbers of reservation with respect to early discount price and regular price. Based on these numbers, we calculate the expected profit and then discuss the optimal number of early discount seat maximizing this profit. Finally we summarize the paper and mention further research problem.

Keywords: airline ticket reservation, early discount price, online reservation, expected profit maximization, transfer percentage of overflowed customers to regular price ticket

EMERGENCY ORDERS IN AN INVENTORY SYSTEM FACING COMPOUND POISSON DEMAND

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We consider the opportunity to use emergency orders to hedge against demand uncertainty caused by discrete compound Poisson customer demand. Such orders incur additional costs compared with normal orders but have much shorter lead time. Axsäter (EJOR 2007) suggests a heuristic decision rule for triggering emergency orders in the continuous-review system where demands not satisfied immediately from inventory are backordered. His decision rule is based on complete information about the present state of the inventory system and it assumes that normal orders are triggered by a (R, Q) policy, where R and Q denote the reorder point and the order quantity, respectively. The rule restricts attention to some demand instants, for example those with no inventory on hand. Whether or not to place an emergency order is decided by applying a single improvement step of a policy-iteration algorithm. Its relative values of the inventory position are determined for the setting where the system is controlled solely by the best (R, Q) policy for normal orders.

We suggest determining the relative values of the inventory position for the setting where the system is controlled solely by the best (R, S) policy for normal orders, where R and S denote the reorder point and the order-up-to level, respectively. A simulation study compares the long-run average costs per unit time of using the relative values suggested by us rather than the ones suggested by Axsäter.

THE FILL RATES FOR A CRITICAL LEVEL POLICY WHEN DEMAND IS MODELED AS A COMPOUND BERNOULLI PROCESS

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In this paper we study a single location inventory system for a single item. The stockpoint has to satisfy two different types of customer demand. Such a situation can occur, for example, in a two-echelon network, where the most upstream stockpoint has to satisfy customer demand directly as well as replenishment orders from other stockpoints. Customer demand is usually seen as more important and therefore has a higher priority. Customer differentiation is also applied in the context for service contracts. There are contractual agreements stating a maximum time interval for the supply of a service part. Depending on the price the customer is willing to pay, the supplier has to deliver within a specified time interval.

For the control of inventory systems with two customer classes, critical level policies are applicable, where low priority customer demand is only satisfied, as long as the inventory level is above the critical level. High priority customer demand is always satisfied as long as there is stock available. Our study is focused on a periodic review system with a critical level, a reorder level and a fixed order size.

Since customer differentiation is often applied for spare parts, we have to consider the special characteristics of them. There are often many periods with no demand between periods with random demand. Such demand patterns are called intermittent and can be modeled with a compound Bernoulli process. Further, service levels play an important role. Therefore, we develop approximations for the fill rates and compare them to existing ones, not specific for intermittent demand. In a numerical study we illustrate, that it is important to take the special demand structure into account and that our approximations outperform others.

Keywords: stochastic inventory model, critical level policy, intermittent demand, fill rate

A NEW HEURISTIC FOR THE DYNAMIC LOT SIZING PROBLEM WITH RETURNS AND REMANUFACTURING

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In the recent years remanufacturing practices have been accelerating due to increasing environmental awareness. Firms implementing remanufacturing practices recover used products returned from customers; and process them into reusable products. Matching supply to demand is more difficult in integrated manufacturing and remanufacturing due to the need of coordinating manufacturing and remanufacturing operations in the context of production/inventory management. Hence, the applicability of traditional production / inventory control approaches in remanufacturing systems is rather limited. This has motivated research efforts towards extending traditional inventory control problems with remanufacturing options. An important problem considered in this context is the economic lot sizing problem with returns (ELSP-R). ELSP-R is a finite horizon problem with dynamic demands and returns where the objective is to minimize the sum of setup costs for manufacturing and remanufacturing, and holding costs for serviceable and return inventories. ELSP-R has been extensively investigated in the recent years and shown to be NP-hard.

This paper proposes a new heuristic for the ELSP-R. The new heuristic builds on the zero-inventory property for manufacturing and all-or-nothing property for remanufacturing. That is, a manufacturing run is undertaken only when the serviceable inventory level is zero; and if a remanufacturing run is engaged, then all items in the return inventory are remanufactured. It is known that the optimal solution of the problem does not always possess the aforementioned properties. Thus, the heuristic corresponds to an over-constrained version of the problem and provides an upper bound for the optimal cost. The paper shows that the over-constrained problem can be solved to optimality by means of a polynomial-time dynamic program, and compares the cost performance of the new heuristic against the optimal cost as well as the earlier heuristics by Teunter et al. (2006) and Schulz (2011). The results show that the new heuristic outperforms the earlier heuristics and provides near-optimal results for all test instances considered. In particular, it yields an optimality gap smaller than 1% over 98% of the test instances. These, all together, suggest that the proposed heuristic is a viable alternative to the optimal policy which also comes with properties that could ease the coordination of manufacturing and remanufacturing operations.

Keywords: production and inventory management; remanufacturing; optimization; economic lot sizing problem; heuristic

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A VENDOR MANAGED INVENTORY MODEL WITH TRANSPORTATION TO GEOGRAPHICALLY DISPERSED RETAILERS

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We consider a vendor that supplies a set of geographically dispersed retailers using the capabilities of being able to monitor the inventory levels at the retailers. Such an arrangement is often coined Vendor Managed Inventory (VMI). The model we develop has some similarities to a Joint Replenishment Problem (JRP). However, in most JRP studies, one cost factor that is not explicitly taken into account is formed by the transportation costs arising from the geographical locations of retailers, in particular when being able to group retailers together in routes. Therefore our paper is focused on developing a more detailed specification of the transport costs than seen in most JRP models. We develop a joint transport and inventory model that take these routing considerations into account. A Markov chain model approach is used. In principle such an approach would require a large number of states if we keep track of all the inventory positions of the retailers. In order to lessen this burden we choose to include geography into our model by using a continuous approximation (CA) approach. The central idea in CA is that, if retailers are more or less uniformly spread across a region, the lengths of the delivery tours can be approximated analytically, meaning that it is not necessary to perform laborious routing computations. We will consider two different types of service areas: a more or less uniformly distributed two-dimensional circular area (the circular city; actually, the shape is not so relevant, but for the sake of convenience, we use this shape) and a one-dimensional area in which the retailers are assumed to be distributed on a line (the linear city). Often, some kind of zoning is used to divide the total delivery area into smaller ones. We assume that a zoning strategy is already in place and we determine, for a given zone, how the inventory levels at the vendor and the retailers are influenced by transportation and inventory costs. The inventory and dispatch decisions determine the degree of vehicle utilization, as it may be optimal to dispatch a vehicle before it is filled up to capacity. We present numerical results on the structure of the inventory control policy as well as comparing various zoning strategies.

Keywords: joint replenishment policies, continuous approximations, markov chain modeling

SEA-BASED MILITARY LOGISTICS FOR AERIAL DISTRIBUTION TO SUPPORT COMBAT UNITS

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The concept of sea-based military logistics emerged in the mid 1990s, and since then some simulation or mathematical programming approaches have been proposed along with various modeling efforts. Because of the complexity and sizes of the mathematical models, an efficient and effective solution method has been desired. In Sea-Based Logistics (SBL), Amphibious Ready Group (ARG) ships are used to provide a sea-base from which combat forces ashore are directly sustained. This paper considers an emerging problem in the area of pure sea-based logistics, which removes the traditional structure of land-based support units. All supplies are stored on the floating sea base, which are relatively safer from enemy attacks. Supplies from the sea-base will be direct delivered by aircraft to combat units in operation. In this paper, we introduce several military SBL models for supporting combat forces ashore. These models are formulated by mixed integer linear programming with a goal of minimizing the number of aircraft takeoffs to reduce the exposure to land-to-air attacks. In addition, we proposed more realistic expanded models from Model 1, considering the backorder and multiple commodities with different weights and volumes. An efficient heuristic algorithm and a genetic algorithm have been developed to solve problems of medium- and large-sized warfare scenarios. In general, the performance of the proposed GA surpasses the proposed heuristic algorithm but the heuristic algorithm also produced relatively good solutions. The computational results showed that the performances of the proposed heuristic algorithm and the genetic algorithm are quite robust. The MIP approach and the proposed heuristic algorithm show a significant increase in computation time as the problem sizes grow. However, the proposed GA shows a robust performance with respect to the variation in problem sizes and can be used to solve the problems within a relatively short computation time regardless of the problem size. It is important to military logistics officers at war time that a way to make a quick decision to any situation is available. These algorithms are useful for military logistics planners to support tactical or operational real-time decision-making. An effort to develop software for warfare simulations based on these SBL algorithms would make an interesting research area.

Keywords: sea-based logistics; inventory; mixed integer program; heuristic algorithm; genetic algorithm

CUSTOMER SATISFACTION AND LEAD-TIME QUOTATION IN AN M/M/1 BASE-STOCK SYSTEM

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In a service system such as a supply chain, customer service and so on, long waiting time of customers leads to the less customer satisfaction, but long waiting time information for customers will make a part of customers leave the system without receiving service and make smaller profit of the system. Thus control of the lead time or delay information is important.

In Savasaneril, Griffin and Keskinocak (2010), the optimal lead time quotation in an M/M/ 1 base stock inventory queue is discussed, which maximizes the system's profit. In this system, if the quoted lead time to the arriving customer is high, then the probability that the customer enters the system and is served is small. In their paper, the model is formulated as a Markov decision process and properties of the optimal lead time quotation policy are discussed. When this optimal policy is applied, however, the customer's satisfaction may be small, because his/her actual waiting time for item may be longer than quoted lead time.

The delay information to the customers and its effect to the customer's satisfaction is formulated in Guo and Zipkin (2007),(2008). In their papers, the utility function of each customer in a single server queue is defined, which shows the degree of his/her satisfaction and includes the probabilistic parameter showing his/her importance for waiting time, and if the value of the parameter is high then he/she is impatientof waiting. They defined several types of delay information and their effects are discussed theoretically and numerically.

In this paper, the effect by the lead time quotation in an M/M/1 base stock inventory queue into the customer's utility function is discussed. The utility function is based on the definition in Guo and Zipkin, and if his/her utility is negative given the lead item information then he/she leaves the system without receiving service, and otherwise enters the system and receives it. The numerical examples show that the optimal lead time quotation policy maximizing system's average profit has low customer's satisfaction, and the other simple quotation policy leads to the greater expected values of customers' utilities although it has a bit smaller system's profit than the optimal policy. In particular, the lead time quotation policy under a base stock sometimes has both more system profit and much customer's satisfaction compared with the optimal lead time quotation policy with the greater number of base stocks.

Keywords: base stock policy, lead time, M/M/1 queue, customer's satisfaction, information

PRODUCTION PLANNING OF A PERISHABLE PRODUCT WITH LEAD TIME AND NON-STATIONARY DEMAND

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We study a production planning problem for a perishable product with a fixed lifetime, under a service-level constraint. The product has a non-stationary stochastic demand. Food supply chains of fresh products like cheese and several crops, are characterised by long, but known, fixed lead times due to maturation processes. Long lead times in combination with non-stationary demand, tend to induce high safety stock levels. For perishable products, this can lead to an increase in outdating. To minimise waste due to outdating, one issues the oldest product first, i.e. a FIFO issuing policy. In case of out-of-stock, demand is backlogged. The objective of our study is to develop a production planning method for a perishable product with non-stationary demand and a long deterministic production lead time, that results in a high service level while keeping outdating and safety stocks low.

For the case of a fixed lifetime perishable product confronted with non-stationary demand, zero lead time and a FIFO issuing policy, Pauls-Worm et al. (2012) formulate an MILP model that determines a stock-age-dependent replenishment cycle policy. Specifically, an α-service-level constraint is applied. In our study, we adapt the MILP model adding a lead time and we determine safety stocks based on the desired fill rate. Based on this adapted model, we develop a heuristic procedure to determine a production plan for a perishable product with a long lead time. As the input demand forecasts become more reliable with an approaching selling date, it may be advantageous to correct the production plan for more accurate forecasts. The procedure is based on a rolling planning horizon in which demand forecasts are updated.

The first results are promising: the procedure allows for relatively low safety stocks and is able to meet the desired fill rate.

Keywords: non-stationary stochastic demand, perishable, lead time, safety stock, fill rate

MILK PROCUREMENT OF A PRIVATE DIARY FIRM: AN ECONOMIC ANALYSIS

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In this paper we study the milk procurement system of a private dairy that buys milk from farmers (primary producers) and through intermediaries and processes them to convert them into value-added products like, butter, ghee, yoghurt etc. As milk collection in India is predominantly collected through cooperatives, milk availability for the private dairy becomes critical and depends on market principles. The intermediary also supplies a part of its milk to the local market. We developed mathematical models to represent the intermediary's opportunistic behavior and the system and obtained expressions for optimal decisions for the intermediary and the dairy. Based on data collected from a private dairy, we carried out numerical analysis to understand behavior of both the intermediary and the dairy.

Keywords: supply chain, procurement, supply chain coordination, supply contract

MANAGING SUPPLY RISK DURING THE LIFE-CYCLE OF TECHNOLOGY PRODUCTS

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Technology firms routinely face the challenge of matching supply with demand in the presence of supply risk. In particular, the microprocessor industry is characterized by short product life cycles, long production lead times, and highly complex and volatile manufacturing processes. Even though every unit of raw material undergoes identical operations, variations in the manufacturing operations may result in large variations in clock speeds of finished processors. In order to managesupply variability more effectively, firms classify processors into different versions (or products) based on the processors' clock speeds and sell these products at differentprice points in the market. This simultaneous manufacturing of different products is often referred to asco-production. Existing literature on co-production systems has frequently studied downward substitution as onepotential response to stockouts. Using downward substitution, firms satisfy unmet demand of low-end products by downgrading excess units of high-end products and selling these at the low-end price. However, empirical research has shown that low-end customers are eventually willing to substitute a high-end product in case their first choice is not available (upward substitution).

In this paper, we show that solely downgrading high-end products to fulfill unmet demand of low-end products may be suboptimal in matching supply with demand. We formulate a two-product co-production model that integrates downward and upward substitution in a hybrid approach. We first analyze and compare the two extreme strategies, "manufacturer-initiated substitution" (MIS), equivalent to downward substitution and "customer-initiated substitution" (CIS), equivalent to upward substitution, and show under what conditions firms should adopt MIS or CIS. Then, we study the hybrid approachand determine the optimal fraction of adopting MIS and CIS. We also show that under certain circumstances a rather indirect CIS strategy becomes optimal where a firm only offers the high-end product. The firm anticipates that a large number of low-end customers are willing to substitute upwards so that offering only the high-end product becomes more profitable.

AN ANALYSIS OF THE EFFECT OF RESPONSE SPEED ON THE BULLWHIP EFFECT USING LINEAR CONTROL THEORY

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In this paper, we use linear control theory to analyze the effect of dynamic inventory policies on the non-stationary performance of order and inventory behaviors throughout a supply chain.

We suggest that inventory reductions -as a means to retain liquidity- represented a common response to the recent financial crisis (september 2008). Furthermore, we postulate that these reductions were extremely synchronized: not only did firms attempt to reduce their stocks, but they did so almost simultaneously. We hypothetize that this behavior played a substantial part in what we can describe as a worldwide bullwhip effect. We call for attention to be paid to the dynamics of inventories and inventory policies, for they represent a substantial source of the observed demand dynamics. Our study attempts to further develop the understanding of these dynamics by taking the managerial behavior towards inventory into account as a fundamental driver of the evolution of demand in a supply chain.

The contribution of our work is twofold; first, we provide an analytical counterpart to our previous research efforts on the usage of system dynamic simulations as a way to capture inventory dynamics throughout entire supply chains (and thus provide accurate forecasting tools for upstream players during periods of strong demand disruptions such as the recent credit crisis). Second, our models extend upon previous work on the control theory/operations research literature by explicitly modeling managerial behavior, long accepted as one of the causes of the bullwhip effect. In linear control models, the orders are a linear combination of the forecast, the inventory gap and the supply line gap. By using different behavioral parameter settings in this combination, we can obtain a variety of order behaviors. We use transfer function analysis to study the structural properties of a single echelon by first investigating the effect of the behavioral parameters on the stability of the system, followed by the transient response of orders (and inventories) to step changes in demand. We then link these echelon models into supply chains and analyze the responses of upstream echelons to downstream changes in demand. Finally, we model inventory reductions in the supply chain and demonstrate their effect upstream.

In this work, we validate and quantify the results from our empirical research, and also gather additional insights on the importance of explicitly modeling on-hand and pipeline inventories, and dynamic inventory-related policies; specially in times of financial turmoil when inventory policy becomes an instrument to increase liquidity.

GLOBAL DUAL SOURCING AND ORDER SMOOTHING

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Motivated by the recent trend of offshoring manufacturing facilities to seek lower production cost, while keeping some costly local facilities to better respond to changes in market demand, this paper studies a dual sourcing policy and characterizes the average sourcing allocation. We consider the total landed cost from origin (combining a cheap but slow source and a fast but expensive source) to destination (finished goods warehouse), including sourcing, capacity and inventory related costs. We adopt a linear control rule that allows an exact and analytically-tractable analysis of a dual sourcing or mixed-mode transportation policy that is easy to implement. Another distinguishing feature of our model is that it captures the leadtime difference between both sources. We provide an exact lower bound formula on the strategic base or offshore allocation when this leadtime difference equals one review period, and a close approximation for longer leadtime differences. This formula provides structural insight on the impact of financial, operational and demand parameters, and a starting point for data-driven decision making. We demonstrate the robustness of our results by showing that this dual sourcing smoothing policy is near optimal in terms of total cost minimization compared to existing single sourcing and dual sourcing models in the literature. We describe under which practical conditions the dual sourcing smoothing policy is advisable and when it can even outperform the other policies.

Keywords: inventory, capacity, dual sourcing, production smoothing, mixed-mode transportation, emergency replenishment

DYNAMIC SUPPLY CHAIN INVENTORY MANAGEMENT UNDER DETERMINISTIC AND UNCERTAIN CONDITIONS: A GENERIC MATHEMATICAL PROGRAMMING APPROACH

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Objectives of study: Inventory management is a key supply chain (SC) activity, enclosing a complex and challenging task. Most published studies deal with simple SC structures (single warehouse that supplies a single product to multiple retailers, usually on a single time period), so, further studies are required to treat real problems.

This work proposes a general inventory management (IM) policy applied to a generic SC. A multi-warehouse, multi-retailer and multi-product SC over a multi-period time horizon is considered. Real world aspects are studied; i) SC policies; ii) lead times; iii) safety stock; iv) lost sales; v) uncertainty.

Materials and Methods: In the SC studied retailers replenish their inventories from warehouses that are replenished from a central warehouse. All storage and transportation capacities are limited and safety stocks as lost sales are considered. Lateral transshipment between warehouses or retailers is allowed.

The proposed IM policy determines both the inventory levels and distribution plans of the retailers and warehouses that minimize the SC costs. Costs include ordering, holding, holding in transit, transportation, transshipping and lost-sale.

The system and the IM policy in study are modeled through a mixed integer linear programming (MILP) model. A Continuous Review (CR) and a Periodic Review (PR) policies are also modeled through MILPs that act in the same system, so as to compare results.

Uncertainty is considered in the IM model through a scenario planning approach. Uncertainty exists on products demand and lead times.

Results: The IM policy outperformed the CR and PR policies. A detailed analysis showed that: i) the IM policy is strongly influenced by changes in lead time, transshipment and safety stock and, therefore, these should be accounted when controlling costs at desired service levels; ii) the IM policy model founds robust solutions in uncertain conditions.

Conclusions: A generic SC over a multi-period time horizon was studied. Lead times, transshipment and safety stocks were considered. The generic IM policy proposed does not use a fixed order quantity nor a fixed period between ordering allowing for lower operational costs when compared with traditional policies. Operational uncertainty was included in the IM policy through scenarios so as to obtain expected costs. We aim in future to generalize operational uncertainty optimization methods for the proposed IM policy.

Keywords: inventory management in supply chain; mixed integer linear programming; continuous review; periodic review, scenario planning approach

INVENTORY STACKING WITH STOCHASTIC ARRIVALS AND DEPARTURES

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We consider an operations optimisation problem in an inventory storage yard for a steel company. The finished products are delivered in batches from the workshops to the yard with a stochastic arrival time.These products,which belong to different customers, have different departure timesand physical dimensions then need to be stacked into storage slots and wait for departures. Lorries arrive at stochastic time within scheduled weeksand retrieve the batch of products belonging to the same customers. Due to the difference between stacking and retrieving sequences, there is often a need of reshuffling such heavy productsduring stacking and retrieving processes. The objective of this study is to minimise the reshuffles so as to improve the operational efficiency.

This problem is similar to the container stacking problem in container yards. The import containers arrive in batch with scheduled time and are retrieved by trucks which arrive in a stochastic sequence, whereas the export containers are transported to the yard by trucks in a stochastic sequence and are loaded on ships in batch with scheduled time. Even though both our inventory stacking and container stacking problems have the same aim of reducing the reshuffles, our problem is more complicated since both arrival and departure processes exhibit stochastic property. Thus our inventory stacking problem is more complicated, but also it offers a new area for research.

In this study, several models are proposed to minimise the reshuffles in different stages of the inventory storage process. The first model assigns each arrival product a slot with the least expected reshuffles in the latter retrieving procedure. By relocating the products to the top of slots with the least potential reshuffles, the second model attempts to minimise the reshuffles when retrieving process eventually occurs. Also heuristics (TIGHT and LOOSE) are developed based on the characteristics of the models to expedite the computation for the industrial application.

We use simulation to compare the performance of different models in various scenarios. A random stacking policy is used to generate the upper bound of performance. When the product quantity is relative small compared with the capacity of the storage yard, the heuristics perform close to the optimal one. When the product quantity increases, the heuristic TIGHT performswell while the heuristic LOOSE runs out of empty slots first and then leads to many reshuffles. The results of this research help the steel company to improve the management of storage yard and dispatch performance.

Keywords: inventory stacking, stochastic process, reshuffles, integer programming

ON OPTIMAL POLICIES FOR PRODUCTION-INVENTORY SYSTEMS: THE COMBINATION OF SET-UP COSTS AND ORDER ACCEPTANCE

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We consider a single-item, one-machine, production-inventory system with compound Poisson demand. There are different demand classes, characterized by (positive) reward and order size. Upon arrival the demand class becomes known, and it has to be decided whether the order is accepted or not. Accepted orders are delivered immediately or are (partially) backlogged if there is insufficient inventory. The machine is either on or off. While on the production rate is constant, while off the production rate is zero. System costs consist of a fixed set-up cost and convex inventory and backlogging costs. Because of the set-up cost we have to distinguish decisions when the machine is on and decisions when the machine is off; the state space consists of two lines, the on-line, with states $(1,x)$ and the off-line, with states $(0,x)$.

The paper explores the structure of the optimal policy. Interesting points to investigate are:

- Is there monotonicity with respect to the acceptance decisions? If orders from class A are accepted in state (p,x), are they also accepted in state (p,y), with $y > x$? And what about the order classes with higher reward and/or smaller order sizes?

- Is there monotonicity with respect to the production decision? If the production is switched on in state $(0,y)$, is it also switched on in state $(0,x)$, with $x < y$?

- What are the differences in acceptance policy between the on-line and the off-line? And what is the influence of the set-up cost?

Interesting related work is that of Ha (1997, 2000). That work is restricted to the lost-sales case and does not include set-up cost. And the model is closer to queueing. Ha gives broad monotonicity results. It appears that in our case such results do not hold that broad, even not in the case without set-up cost. It is interesting to investigate the reason for this difference.

The methods used in the paper have been developed by Van Foreest and Wijngaard (2010) and are used there to prove monotonicity of production decisions for the case without order rejection possibilities.

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A JOINT OPTIMIZATION PROBLEM OF PREVENTIVE MAINTENANCE INTERVALS AND SPARE PARTS INVENTORY FOR MULTI-UNIT SYSTEMS

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In this paper, we deal with a joint optimization problem for preventive maintenance intervals and inventory control of spare parts considering multi-unit systems with complex structures. A block replacement policy is applied to maintain all components at the same time. It is necessary to consider the maintenance schedule to reduce the waiting time due to the constraint of maintenance resources when we determine preventive maintenance intervals for multi-unit systems, and (s, S) inventory policy for spare parts is used. The decision variables are the starting points and preventive maintenance intervals, the reorder point and the order-up-to level of spare parts in this paper. The system life cycle cost and availability are used as optimization criteria and estimated by simulation. A meta-heuristic algorithm is proposed to find the near-optimal solutions that minimize the system life cycle cost and satisfy the required system availability. Numerical examples are also studied to investigate the effect of model parameters to the optimal solutions.

Keywords: availability, maintenance policy, spare parts, simulation, meta-heuristic algorithm

Forecasting for Inventories

ANALYSIS OF THE BULLWHIP EFFECT IN AN INTERMITTENT DEMAND CONTEXT

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One of the major problems associated with supply chain forecasting is the amplification of demand variability as orders move upstream in a given supply chain. This phenomenon, termed as the Bullwhip Effect, has received considerable attention in the academic literature due to its implications for planning and customer responsiveness. Many papers in the literature analyse mathematically the Bullwhip Effect by using ARIMA (p, d, q) models. However, such analysis cannot be applied in an intermittent demand context.

This research investigates the Bullwhip Effect for intermittent demand through the consideration of a class of Integer Autoregressive Moving Average (INARMA) models. INARMA models have previously been applied in other contexts such as medical science and economics, but some attempts have recently been made to use such a modelling approach to forecast intermittent demand.

With the help of simulation on theoretically generated data, we calculate the increase in variability by using the ratio of the variance of the demand to that of the orders in a two stage supply chain. Subsequently, the variance amplification is assessed on empirical data.

Keywords: supply chain modelling, bullwhip effect, INARMA processes, intermittent demand

FORECASTING IN THE PRESENCE OF INVENTORY OBSOLESCENCE: EMPIRICAL FINDINGS AND IMPACT OF THE SMOOTHING CONSTANTS

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Most work in the area of intermittent demand forecasting is based on Croston's estimator that relies upon exponentially smoothed demand sizes and inter-demand intervals. This method has been shown to be biased and since then a number of variants have been introduced in the literature including a very recent proposition that links forecasting to the issue of obsolescence.

The method under concern updates the demand probability instead of the demand interval, doing so in every period and has been shown theoretically to be unbiased (for all points in time).

However, its empirical performance has not been investigated yet and this constitutes the objective of our work. In this paper, we address the empirical performance of this method as well as other methods used in an intermittent demand context, paying particular attention to the effects and implications of smoothing constant values employed for updating purposes. We do so by means of experimentation on large empirical datasets from the military sector and automotive industry. The results enable insights to be gained into the comparative merits of the various approaches in conjunction with the smoothing constants used. The paper concludes with an agenda for further research.

Keywords: intermittent demand, inventory forecasting; smoothing constants, empirical analysis

FORECASTING DEMAND FOR SLOW-MOVING SPARE PARTS: A COMPARATIVE STUDY AT THREE COMPANIES

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Traditional forecasting methods such as moving average, single exponential smoothing, and double exponential smoothing, are known to be inapproriate for forecasting demand of slow-moving spare parts, because they do not incorporate explicitly the potentially high number of periods in which no demands occur. Several methods have been proposed that can cope with such periods, of which we mention Croston's method (Croston, 1972), the Syntetos-Boylan Approximation (SBA, by Syntetos and Boylan, 2001), and the empirical method by Porras and Dekker (2008).

In the latter method, if L is the average lead time in periods, then samples are taken from the historical demand of size L periods. Taking many of such samples, an empirical distribution arises. We propose an additional empirical method in which we sample from the historical lead times and use this historical lead time instead of L. Since huge variations in lead times can be observed for certain parts, such a change may result in better forecasts.

We compare the performance of the seven above-mentioned methods on a data set that consists of five-year historical data from three different companies. Whereas most comparative studies focus on performance measures like the mean squared error, we focus on the resulting inventory control.

We look at various characteristics of the parts and find that the two characteristics that inuence the performance of the forecasting methods are the average inter-demand-interval and the squared coefficient of variation of demand size. This is in line with observations of Boylan et al. (2008), but our classification is different from theirs: they do not consider empirical methods, whereas we find that that the empirical methods are the best performing methods for parts with a high average inter-demand-interval (> 4) and a low squared coefficient of variation of demand size (< 0:3). In this category of parts, our method is slightly better than that of Porras and Dekker (2008). On all other parts, SBA performs best.

Our work is very useful for companies that need to forecast spare parts demand. To the best of our knowledge, it is the most extensive comparative study in terms of number of forecasting methods considered and size of the data set. Our new forecasting method and the classification scheme have practical relevance as well.

Keywords: spare parts, inventory control, demand forecasting

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EMPIRICAL DISTRIBUTION FUNCTIONS FOR INVENTORY MANAGEMENT

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In many inventory management systems, the characterisation of the distribution of demand is challenging, because the data do not conform to any of the standard distributions. In this case, Empirical Distribution Functions may be used to forecast the percentiles required for inventory control.

Three types of Empirical Distribution approaches are examined in this paper: non-overlapping blocks, overlapping blocks and bootstrapping. Their theoretical properties are compared, and simulation analyses are conducted to determine the effect of key parameters on estimation performance. This includes the effect of the number of historical observations, lengths of blocks, the underlying distribution of demand, and the percentile being estimated. The effects of these parameters on inventories, for each of the three approaches, are also evaluated.

Keywords: empirical distributions, forecasting

FORECASTING OF PRODUCTS WITH INTERMITTENT DEMAND: A CASE STUDY FROM PHARMACEUTICAL INDUSTRY

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In practice firms face the problem of intermittent demand. In this case the number of observations is very rare compared to the number of periods with positive demand. The classical statistical forecasting methods, such as simple exponential smoothing or regression models, are not appropriate to forecast demand in this case. The aim of the paper is to analyse the forecasting system of a Hungarian pharmaceutical firm. We have investigated more than 12,000 products of the enterprise with the known grouping system of Syntetos and Boylan. We have used the methods of Croston, Syntetos-Boylan and Levén-Segerstedt. On the basis of the forecasting we have determined the safety stocks of the firm.

Keywords: forecasting, sporadic demand, intermittent demand, statistical methods, case study

LINKING CUSTOMER-SPECIFIC DEMAND INFORMATION INTO SPARE PARTS INVENTORY MANAGEMENT - A CASE STUDY

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Today it is common that a big part equipment manufacturers' business consists of maintenance and spare part services. The objective of this study is to provide management decision support in a situation which an equipment manufacturer is selecting inventory policies for its' spare parts. Spares are a challenge for inventory management, because the demand is typically intermittent and low in volume. On the other hand, close contact with the customers may offer possibilities to predict demand on the basis of information requested directly from the customers, and this is an issue that has been rather under-discussed in former research. It is beneficial to be able to identify the situations where the customer demand seems to follow a regular pattern, and where customer-specific demand information could be of value in demand forecasting. This is where classifying demand patterns can be of help.

Literature presents several models for spare parts classification. A recent review [1] lists 27 models, but only two models take customer-related criteria, namely part specificity, into account. In our model customer specificity and demand frequency are the primary criteria in the process of determining potential inventory policies.

This study is a participatory single case study. The case company is a large global equipment manufacturer, that is currently expanding and re-designing its spare parts business. The classification model was developed in cooperation with the case company, and was tested with 48 month transaction data of one product line, concerning 13 000 items.

The main contribution of this study is describing how the spares can be classified on the basis of past demand data, and how this data analysis can be linked into managerial decision process of defining inventory policies. It offers a managerial benefit by focusing development resources - The model facilitates finding the most potential pilots for both collaborative and statistical forecasting approaches.

Keywords: spare parts; inventory management; forecasting; intermittent demand; supply chain

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AN ALTERNATIVE IMPLEMENTATION OF CROSTON'S METHODOLOGY THROUGH A WIDE RANGE OF TIME SERIES METHODS

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A number of research projects have demonstrated the difficulties of obtaining accurate demand demand forecasts in a spare parts context due to the sporadic nature of the relevant demand patterns. Croston's method is a widely used intermittent demand forecasting approach, which decomposes the demand series into two components: the demand sizes and the inter-demand intervals. In this paper, we focus upon the evaluation of different alternative implementations of Croston's method on empirical intermittent demand data. In more detail, performance is assessed on monthly demand data for 8,000 Stock Keeping Units based on a wide range of performance metrics.

The original Croston method uses Single Exponential Smoothing (SES) for extrapolating separately demand sizes and inter-demand intervals. However, It is certainly feasible to combine different forecasting methods for the demand size and demand intervals in order to produce the final forecast of demand per period. In this paper, we investigate every possible combination for forecasting the constituent elements separately, using a wide range of time series methods. In particular, and in addition to SES, we consider: the Naïve method, Simple Moving Average, Simple Linear Regression, Holt Exponential Smoothing, Damped Exponential Smoothing and the Theta Method.

The smoothing parameters of SES, Holt, Damped and Theta are optimised through the in-sample minimization of MSE. Furthermore, we are considering optimization of Simple Moving Average parameter through in-sample rolling forecasting evaluation. All the possible combinations for each SKU are evaluated through the following performance metrics: Mean & Median Error, Mean & Median Absolute Error, Mean & Median Absolute Scaled Error, Mean Squared Error, and Geometric Root-Mean Error. Preliminary results indicate that there is room for improvements when different extrapolation methods are combined, especially regarding both accuracy and bias, especially when data with high intermittency are considered.

Keywords: intermittent demand; demand forecasting; croston's method; exponential smoothing; accuracy evaluation; forecasting competition

INVENTORY FORECASTING: APPROACHES TO DEALING WITH SEASONALITY

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Traditionally, seasonality is estimated from an item's own data history resulting in the determination of individual seasonal indices (ISI). However, when the data is noisy and the length of history is short, ISI may not provide accurate forecasts. A possible answer to this challenge is to use the knowledge of demand at some aggregate/group level to improve forecasts at the individual level. This approach is usually referred to as group seasonal indices (GSI) and an important assumption in its application is that a grouping mechanism is available. Our work provides extensive empirical evidence on the comparatives merits of these approaches both with regards to forecast accuracy and inventory implications. The formation of seasonal groups is also explicitly addressed and liked to performance results.

Keywords: inventory forecasting; seasonality; empirical analysis

THE EFFECT OF DEMAND PLANNING PROCESS ON OPERATIONAL RISK IN SUPPLY CHAINS

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The activities performed in a supply chain ought to satisfy customers' needs and expectations. Therefore, the companies in a supply chain take specific actions in order to determine the exact possible future demand.

The correctness of demand forecasts is determined by several factors which should be identified and analyzed in a planning process. The demand planning process is defined as a sequence of actions which may be grouped into three stages, namely gathering of information about a future demand, use of quantitative or qualitative forecasting methods and verifying available resources enabling to determine a feasibility of forecast.

The actions undertaken in a demand planning process may be disrupted by a number of risk factors. These include process, human, technological risks and environmental risk.

The process risk may negatively affect the efficacy of internal processes, human risk results in disruptions caused by intentional and unintentional employees' behavior or lack of skills and small number of staff in a department responsible for a demand planning process, whereas the technological risk may have negative consequences for an operation of information systems and communication infrastructure. The environmental risk may cause the disruptions located outside the supply chain.

The goal of the paper is to identify the factors of operational risk in a demand planning process and to offer solutions enabling to eliminate and mitigate their negative effects.

In order to obtain the goal of the paper a survey of 150 manufacturing and trade companies operating in supply chains has been conducted and statistical analysis has been performed. Having conducted Principal Component Analysis (PCA), the constructs reflecting risks factors and their effects have been identified. The results of the study show that the examined supply chains may be grouped into classes with a distinct strength of disruptions caused by the operational risk factors. Based on the study, necessary strategies for supply chains have been offered in order to eliminate or mitigate the disruptions in a demand planning process.

Keywords: disruptions, planning process, demand, risks, supply chain

FORECASTING DEMAND DURING PROMOTIONS FOR PERISHABLE ITEMS

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In this paper we develop and test a regression model for promotional demand of perishable items in a retail environment. Based on a literature survey several independent variables are identified which are incorporated in the model. Special emphasis in the model is on the impact of price discounts for perishable items. Earlier work has indicated that threshold and saturation effects may take place, but these studies either focused on general merchandise (e.g. sportshoes) or on dry groceries and were based on data for a few products only. Customers might react differently on promotions for perishable items, for example due to the fact that perishable items may be consumed only for a limited amount of time. We investigate how to incorporate these price discount effects in a regression model and determine based on a large number of promotions for a wide variety of perishable items (including bread, dairy, meat and salads) whether these threshold and saturation effects also hold for perishable items and if so, what the typical values are for these threshold and saturation levels for perishable items. The study is based on empirical data from a retail chain operating many stores in The Netherlands. The Mean Absolute Percentage Error of the forecasts for promotional demand is on average 20% lower when the developed regression model is used compared to the current forecasts made by the retail company. Price discounts below 20% are shown to have no significant effect on demand during promotions.

Keywords: perishable, promotion, price discount, retail, inventory, demand, forecasting

Special session: Emergency Actions in Inventory Management

NEGOTIATED TRANSSHIPMENT PRICES

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Transshipments among two retailers ordering from a manufacturer at the beginning of a season are studied. Retailers dynamically negotiate for transshipment prices and consider sending transshipments one-by-one during the season. They also compete for demand as an unsatisfied customer at a retailer may visit another retailer. We initially allow for transshipments before a stock out and then prove that retailers can maximize their profits without such preventive transshipments. We determine negotiated transshipment prices for various retailer power settings, the associated optimal transshipment policies, and the equilibrium orders from the manufacturer. Resulting transshipment pricescan be static or dynamic depending on retailer powers. Transshipment policies are always dynamic as they depend on the time remaining in the season. They are based on threshold values that are independent of retailer powers. These transshipment prices, policies, and orders completely determine retailer actions. We also study mechanisms to coordinate retailers' transshipment and ordering decisions. We first prove that negotiated transshipment prices coordinate transshipment decisions. Next, we provide a simple and transparent purchase cost sharing mechanism to coordinate orders for the case of static and coordinating transshipment price. This mechanism eliminates independent retailers' incentives to order too much by appropriately increasing the unit purchase cost. We illustrate how this mechanism can be made Pareto-improving for retailers. Profit improvements obtained by coordinating the ordersin addition to transshipments are also reported. To our knowledge, this paper is the first to study independent retailers' transshipment price negotiations after each demand arrival and to hierarchically address the coordination of transshipments and orders.

OPTIMAL ASSORTMENT PLANNING FOR RETAILERS USING TRANSSHIPMENTS

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Transshipments between retailers may help them to satisfy their customer demand timely and at a lower cost then receiving emergency shipments from the manufacturer in case of stock unavailability in their own stores. While the effects of considering transshipments along with inventory decisions are extensively investigated in the literature, transshipments may also affect more strategic level decisions such as assortment planning. In this study, our objective is to find the optimal product assortments in a centralized retailer system, in which customers can have a visited retailer to transship a product from another retailer when the product is not available at the original retailer. We use an exogenous demand model for the products in assortment menu. If a product is not carried by any of the retailers in the system, then it is considered that a customer can be willing to substitute his/her demand with another product, while substitutions are limited to one per customer as it is common in the literature. The substituted demand can be either directly satisfied from the retailer's own inventory or again requested from another retailer as transshipment. The optimal assortments of retailers are investigated to maximize the joint profit, which is composed of customer sales profit from both direct sales and transshipped units and cost of keeping the products in the retailer assortments. We show that when the products in the main assortment menu have symmetric margins then both the total and common assortments of retailers are from the popular product set (ordered according to their demand rate) at the optimality. Furthermore, by showing more detailed properties of the optimal assortment, we propose an algorithm to find optimal assortments that is a linear function of the number of products in the assortment menu. We then extend the model to consider retailer-specific product demand rates. We show how the optimal assortments change under this retailer-specific demand rates.

INVENTORY CONTROL WITH DUAL-SOURCING UNDER YIELD UNCERTAINTY

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Objective of Study: In this paper we consider an inventory model with yield uncertainty. i.e. uncertainty in the quantity of orders that will be received or materialized. Reasons that contribute to this uncertainty include damage during transportation, capacity issues and quality issues. Our model is a dual-sourcing model with an expedited and a regular supplier. The two suppliers have different lead times. Moreover, the expedited supplier always delivers the ordered quantity, whereas the quantity returned by the regular one is uncertain. To the best of our knowledge, this model has not been studied before in the literature. Since the optimal policy for the model without yield uncertainty is already complex and computationally intensive, we study an easily implementable and often near-optimal heuristic policy which is called the Dual-index Order-up-to Policy (DOP).

Methods: For the model where all the ordered goods are received, DOP tracks the inventory positions for both sourcing channels. In every period, an expedited order is placed to restore the expedited inventory position to its target level. After this, a regular order is placed to restore the regular position to its target. One major challenge in our model is the difficulty of tracking the exact inventory positions. To overcome this, we define a virtual demand in each period by adding the unmaterialized order quantity of the current period to the real demand. Furthermore we assume that all the items ordered based on the virtual demand are delivered. By doing so, we react to the supply uncertainty by changing the order quantities in the successive periods.

We prove that, for any fixed difference between the order-up-to levels, our model is equivalent to a newsvendor problem. To solve this newsvendor problem, we need the distribution of the sum of virtual demands and the excess of expedited inventory position above its target level. In our case, the virtual demands are dependent. We approximate the distribution of the sum by modeling it by a discrete time Markov chain (DTMC). Under the assumption of a binomial distribution for the yield uncertainty variable, we prove that the transition probabilities of this DTMC can be easily approximated.

Numerical results: The performance of the heuristic policy in different scenarios is tested and compared with that of the optimal policy obtained from a Markov decision model for small instances.

Keywords: dual-sourcing, yield uncertainty, inventory management, dual-index order-up-to policy, lead time

WHAT DOES THE PUBLIC TOLERATE? BALANCING BETWEEN COST OPTIMIZATION AND WORST CASE SCENARIO IN EMERGENCY SUPPLY

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Emergency supply chain management is often in the focal point of public scrutiny. The pre-positioning of resources based on expected cost minimization may result unacceptable high shortage and supply cost in case of some scenarios which have very small probabilities. This may be a major disadvantage, since any chance for huge loss is hardly tolerated by public opinion. However, planning for the worst case scenario, the difference (the regret) between the cost of the overall optimal solution and the cost of the best solution for the specific scenario is unacceptably large. To decrease the loss for the worst-case scenario, the min-max regret criteria could be applied for the pre-positioning decision. That could result a public support but an unacceptable high expected cost and high potential for unused resources since an unfavorable scenario with very low chance would dominate the solution. We seek a compromise between the worst-case and average cost consideration or equivalently, a compromise between the min-max regret and the expected regret criteria.

The so-called p-reliable regret solution we use is a trade-off between average and worst-case scenario. To avoid the dominance of a single or multiple worst case scenarios we suggest a model that endogenously selects a subset of the scenarios whose collective probability of occurrence is at least 100p%. So it is 100p% sure that the regret will be no more than that found by the model. Our p-reliable regret model helps to find the best alternatives for different reliability preference levels selected by the decision makers.

We apply the above decision criteria to a disaster supply chain problem for hurricane scenarios. We coordinate the two stages, the preparedness and response decisions, in a large hierarchical emergency supply chain. In the first stage decision the expected cost of the second stage is included which is influenced by the first stage decision. The formulated two-stage stochastic program is solved for pre-positioning and distributing supplies under uncertain scenarios of disasters. The solutions provide compromise between higher pre-positioning vs. expected response cost. The decision makers can utilize the major advantage of our parametric model that it provides a set of solution alternatives that dominate the decisions on different reliability levels.

CAPABILITIES INVESTMENT VERSUS PREPOSITIONING INVENTORY: A NEW APPROACH TO DISASTER PREPAREDNESS

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Disaster preparedness has been recognized as a central element in reducing the impact of disasters worldwide. However, donors are reluctant to finance such efforts, as there is no certainty that a disaster will strike. Usual methods of preparedness, such as prepositioning of supplies in countries prone to disasters, are problematic because they require high investment costs at various locations, due to the high uncertainty about the timing and location of the next disaster. Product expiry is a major problem, as there is no inventory turnover (Whybark, 2007). Therefore, Van Wassenhove (2006) proposes relief organizations to invest in effective disaster management capabilities, such as human resources, knowledge management, process management, resources and community. Investing in such capabilities instead of physical assets has several benefits. First, in opposition to prepositioning supplies in specific locations, such capabilities acquired by the organization can be used worldwide. Second, these capabilities, in particular those related with import processes, allow organizations to deliver supplies quickly from a central warehouse in case of disaster. Finally, investments in capabilitiescost less than prepositioning supplies in large quantities in many locations.

In this paper, we analyze the effect of investing in these disaster management capabilities, through a system dynamics model. We model the delivery process of a therapeutic food item during the immediate response phase of a disaster. By comparing a standard import scenario with one where investments in capabilities have been made, we quantify the improvement potential of such preparation efforts (i.e., lead time and inventory reduction).

We find that with capabilities investment, goods can be delivered to beneficiaries almost as fast as if supplies were prepositioned in the country, but at lower inventory costs (lower opportunity costs and physical holding costs, less product expiry and obsolescence, etc.). Transportation costs are higher, but occur only where the disaster strikes, and not in each country where inventory is prepositioned.

The managerial implication of our research will encourage relief organizations to invest more into capabilities instead of prepositioned physical inventories during the preparedness phase of a disaster. Because of lower costs and risks involved, donors are encouraged to finance such pre-disaster efforts which have a strong potential to improve disaster response.

Keywords: Humanitarian logistics, disaster preparedness, inventory prepositioning, import barriers, system dynamics

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THE IMPACT OF DISASTERS ON SUPPLY CHAIN INVENTORY MANAGEMENT

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Objectives of study: Most companies and organizations have incorporated the impact of various disasters and crises on their supply chain design in the name of risk management, business continuity planning, crisis management, and disaster recovery planning. Since the Great East Japan Earthquake on March 11, 2011, Most Japanese companies and organizations have been struggling with the recovery of their businesses and reconsidering their supply chains. This study intends to show some ideas on how to develop resilient supply chains that are good at coping with disasters and crises, focusing on the location of production and inventory.

Materials and Methods: The study starts with reviewing the frameworks of supply chain management and the new concept of the resiliency of supply chain, and identifies the key elements for resilient supply chain. The rationale for the elements is found from the various sources such as journal articles, press information, and the interviews with managers responsible for restructuring their supply chains.

Results: Facing with high uncertain in supply, companies should diversify the risk of supply chain disruption and design agile supply chains. They need to build risk and crisis management capabilities under the leadership of top management to formulate their business continuity planning. Key elements for resilient supply chains are redundancy and flexibility as well as the change of organizational culture. The redundancy orients toward risk diversification by carrying excess inventory at different locations, securing second sources, and diversifying supply sources. Companies and organization can enhance their flexibility by adopting standardized processes, changing sequential processes into parallel processes, and adjusting their procurement strategy with the relationship to suppliers, which contribute to increasing their agility.

Conclusions: One possible way to build a resilient supply chain is to map constituent activities and detect the possible sources of risk and critical chains, which gives a basis for strategic decisions on inventory location and supply base such as criteria for supplier selection and the explorative development of supplier relationship and inventory locations.

Keywords: supply chain; inventory management; risk management; business continuity planning; disaster recovery planning

EMERGENCY LATERAL TRANSSHIPMENTS IN INVENTORY SYSTEMS WITH POSITIVE TRANSSHIPMENT LEADTIMES

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Objectives of study: Consider a manufacturing company that provides its customers with spare parts. For example, a packaging-machine producing company often also acts as a provider of spare parts to its customers when a random failure has occurred in a packaging machine situated at a customer site. When a failure at a machine has occurred it is crucial to replace the failured spare part quickly in order to maximize the up-time of the customers' production system. In this paper we consider lateral transshipments between the customer sites in order to reduce downtimes at the customer sites.

Materials and Methods: We consider a single-echelon continuous review inventory system for spare parts with two parallel locations. Each location faces independent Poisson demand and backorders are allowed. In this paper we consider the possibility of lateral transshipments between the locations. The transshipment leadtime is positive and deterministic, and there is an additional cost for making a transshipment. We suggest a transshipment policy which is based on the timing of all outstanding orders, and develop and solve a heuristic model by using theory and concepts from nonhomogeneous Poisson processes and also partial differential equations.

Results: Our transshipment policy was evaluated in a simulation study, from which we can conclude that our model performs very well. From a strategic point of view, we investigated the impact of using a standard lateral transshipment model with negligible transshipment leadtimes when optimizing base stock levels for a corresponding system with non-zero transshipment leadtimes. The results indicated that there may be a substantial cost increase when using such standard transshipment models when optimizing base stock levels, although the transshipment leadtime is relatively short.

Conclusions: In this paper we have presented a new way of modeling lateral transshipments in inventory systems with non-negligible deterministic transshipment leadtimes. Our solution technique is approximate since the demand stream at each location, when lateral transshipments are allowed, is approximated as a nonhomogeneous Poisson process. Since lateral transshipment leadtimes are positive, a transshipment policy was evaluated which takes pipeline information into account. As a spin-off from our modeling technique, this paper extends the combined backordering and lost sales model considered in Moinzadeh (1989).

Keywords: inventory control, lateral transshipments, emergency replenishments, pooling, stochastic

VALUE OF INFORMATION SHARING IN AN INVENTORY SYSTEM WITH LATERAL TRANSSHIPMENTS

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We study the value of horizontal information sharing in a decentralized service parts management system. The service centers operate independently but collaborate through inventory pooling.When a demand for a service part occurs at a location, the service center either meets the demand from stock, or makes the customer wait until a part is available, or requests a part from another service center. In this setting, we quantify the benefit of inventory level information. We first determine a service center's operating policy under various information sharing schemes through partially-observable Markov decision process model. Then we identify the conditions under which sharing information is most beneficial through numerical analysis. Analysis show that information on inventory levels is valuable when the commission payment is dynamically negotiated upon each part request, and unit profit is low. Contrary to intuition, when cost of requesting a part from the other service center or cost of rejecting a customer is high, value of information may be limited.

Keywords: information sharing, service parts management, decentralized inventory systems, inventory pooling, lateral transshipment, partially observable Markov decision process

EMERGENCY PROCUREMENT PLANNING IN A SINGLE-PERIOD PROBLEM

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Single-period stochastic demand inventory (newsvendor) problem is a building block for more sophisticated inventory control models in the literature. Commonly it is assumed that excess demand is lost when the demand during the selling period exceeds the stocking quantity of the product. However, in some cases it may be possible to take a recourse action and satisfy all demand by tapping an emergency supply source. In this paper we consider a variant of this problem, and investigate the optimal ordering policy when both demand and supply are stochastic. Our study of a newsvendor facing supply risk as well as price-sensitive retail demand contributes to the growing literature on supply chain risk management. The dependence of retail demand on price necessitates finding optimal values of both retail price and order quantity in the maximization of expected profit. We show several properties of the optimal solution. Using additive and multiplicative demand models, we explore how the optimal order quantity and price vary in response to changes in the demand and cost parameters.

Keywords: newsvendor; supply uncertainty; pricing; emergency supply; supply chain management

Special session: Modelling and Simulation of Multi-Echelon Inventory Systems

PRICING AND INVENTORY DECISIONS IN A DUAL-CHANNEL SUPPLY CHAIN WITH LATERAL TRANSSHIPMENT

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Recently we have seen that the rapid development of e-commerce around the world has made it easier for many manufacturers who traditionally distribute their products through retailers to engage in online direct sales. Internet-based electronic marketplace (e-marketplace) plays a particularly important role in e-commerce. In e-marketplace, the searching and transactions costs are low, which attracts buyers and sellers from all around the world to the e-marketplace.

In this paper, we assume that the manufacturer owns the e-marketplace and can directly sell his products through this e-marketplace. At the same time the manufacturer still uses the retailers to sell his products. This will create the competition between the two channels. First is the price competition, the channel with lower price will attract the other channel's customers and decrease the other channel's demand. Second is the inventory competition. Since the demand is uncertain, if a channel is stockout, his customers will be attracted by the other channel with stock in hand.

Actually, there is indeed an emerging body of literature that deals with the competition between two channels. However, to the best of our knowledge, it has not been investigated to the dual-channel with lateral transshipment. In this paper we will consider the lateral transshipment between two channels. If one channel is stockout, he can requestthe other channel with stock in hand to satisfy the demand to the utmost by paying the transshipment charges. But the other channel can agree or reject this request according to his profit maximization requirement. Hence, the difficulties are to decide the transshipment price and quantity so that the lateral transshipment can be implemented and the dual-channel supply chain can be coordinated.

In this paper, we will construct the mathematical models and derive the optimal decisions about the price and inventory in a dual-channel supply chain with lateral transshipment and uncertain demand. Also, we will offer the optimal transshipment strategies including transshipment price and quantity decisions under supply chain coordination.

Keywords: pricing; inventory, lateral transshipment, dual-channel supply chain, coordination

CONSIGNMENT STOCK POLICY FOR A TWO-LEVEL SUPPLY WITH AN IMPERFECT PRODUCTION PROCESS WITH AND WITHOUT RESTORATION INTERRUPTIONS

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The consignment-stock (CS) policy is a business practice where a buyer's inventory is managed its vendor. Such CS has shown to be a profitable stock management approach especially when operating in uncertain environments where delivery lead times and/or market demand vary over time. CS has not been investigated analytically until its introduction into the automobile industry and moreover until the work of Braglia and Zavanella (2003). The CS literature shows that some studies relaxed some assumptions inherent in the model of Braglia and Zavanella (2003) so as to gain a better understanding of CS as a policy, its benefits, its drawbacks and implications, and implementation issues.

One main issue that has been addressed within supply chain coordination is imperfect production where a vendor's process generates defects that are either reworked or scrapped items. This issue has not been investigated within the scope of a consignment-stock policy, which is the main driving force for this study. This paper extends the model developed by Braglia and Zavanella (2003) by relaxing the assumption of a perfect production process.

A mathematical model is developed that allows for various managerial decisions with regards to the imperfect items. The model seeks to determine an optimal production batch quantity and the optimal number of shipments accommodating the various production scenarios with the objective of minimizing the supply-chain system's total costs (maximizing profits). The developed model introduces imperfect items as a result of the possibility that a production process may go 'out-of-control'. The resulting imperfect items may be scrapped at no cost, scrapped at a cost, or sold to a secondary market for a marginal profit. In addition, the imperfect items may be scrapped, under any of the above scenarios, instantaneously or at the end of the production cycle. Further, imperfect items can be re-worked if required. Understanding the nature of different industries and businesses, the aforementioned managerial decisions are incorporated in the model giving it the flexibility required to adapt to business' production situations and needs. Moreover, the model is extended to introduce process interruptions for restoring the process to an 'in-control' state.

Significant findings include that the introduction of imperfect items to the consignment stock model increases the number of items per batch, reduces the number of batch shipments per cycle, as well as reduces the overall cycle time. Further, results show that regardless of the production scenario considered, the application of minor setups for restoration reduces the overall cost of the system. The most noteworthy reduction in cost is in the production scenarios that consider re-work. The various managerial decisions considering the holding of imperfect items and the consequent actions to be taken have little impact on the optimized decision variables and the resulting model performance.

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INTRODUCTION OF PARAMETER RATIOS TO A SIMULATION MODEL OF A CLOSED-LOOP SUPPLY CHAIN WITH CUSTOMER-OWNED STOCK

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Companies outsource the spare parts provisioning for their machines and vehicles to maintenance, repair, and overhaul providers (MRO-providers) as common pooling of spare parts saves costs. Because of the high costs of spare parts, broken parts are repaired and put back into stock, forming a closed-loop supply chain.

To reconcile the replenishment time, when there is an urgent spare part request, customers keep one piece of a crucial spare part at their location for immediate replacement of a failed part. The closed-loop supply chain is a two echelon system comprising the central warehouse of the MRO-provider and the warehouse at the customer location. The delivery time from the central warehouse to the customer warehouse is called replenishment time. The sum of time to repair the part in the shop and the transportation times to and from the shop is called the repair time.

To date, MRO-providers do not take into account the customer-owned stock when planning their inventory levels, since the spare parts at the customer location are the customer's property. A simulation model was built to analyze the effects of the customer-owned stock on the supply chain. Published research findings show that disregarding of customer-owned stock incurs overstocking at the MRO-provider warehouse. Reducing MRO-supplier inventory due to customer-owned stock in the supply chain, fees for spare parts supply for the customers can be lowered.

Carrying on this research two ratios are introduced to the simulation model. The ratio Rho is the average time between two requests divided by the sum of the repair time and the replenishment time. Xi is the ratio of the replenishment time and the repair time. Keeping these two ratios constant, the supply chain performance also stays constant. When the time between two requests is shortened but at the same time the repair and replenishment times are adapted to keep Rho and Xi constant, the service level at the customer location does not vary.

The definition of the ratios Rho and Xi reduces the number of input parameters and facilitates the handling of the simulation model, when conducting experiments. For the MRO-provider taking into account customer-owned stock becomes easier using these ratios, because the number of scenarios to investigate decreases significantly.

Keywords: inventory, spare parts, simulation, multi-echelon, closed-loop

SIMULATION MODEL TO ANALYZE BULLWHIP EFFECT UNDER CLASSICAL AND INFORMATION SHARING ORDERING POLICIES

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The lack of coordination among supply chain members and the local optimization of each member for his own benefits without considering the impact on other members cause inefficiencies in supply chains. Bullwhip effect is one of these inefficiencies. Bullwhip effect has been defined as the amplification of demand information as it moves upstream the supply chain. This distortion in demand information leads to excessive inventories, insufficient capacities and high transportation costs.

Extensive research has been done in order to identify the main causes of bullwhip effect. Ordering policies have been reported as one of the important operational causes of bullwhip effect. This paper investigates the impact of various classical ordering policies on inventories behavior in a supply chain through a simulation study. In addition, a proposed ordering policy that relies on information sharing is proposed to mitigate the bullwhip effect and overcome the problems of classical ordering policies. In the proposed policy, the information of customer demand and inventory adjustment is shared among supply chain partners in a decentralized way. A simulation model is built for a four-echelon supply chain, with deterministic ordering and delivery lead times, in order to quantify the supply chain dynamic performances under the different ordering policies, especially on the inventories.

The simulation results show that the performance of the inventories in the supply chain is always instable under the classical ordering policies. The ordering policies that update its parameters corresponding to demand changes such as Order Up To replenishment always result in high bullwhip effect, high average inventory level, and high variance of inventory level. The policy that sends fixed ordering quantity such as (R, Q) can eliminate the bullwhip effect but fails to recover supply chain performance in terms of inventory level. The proposed ordering policy based on information sharing succeeds to mitigate the bullwhip effect and achieve an acceptable performance in terms of both average and variance of inventory level.

In general, the proposed information sharing ordering policy realized a better performance than the classical ordering policies. This opens the way for designing new ordering policies based on information sharing to handle the problems of classical ordering policies.

Keywords: supply chain; bullwhip effect; ordering policies; information sharing; inventory; simulation

PARTIAL OR COMPLETE DELIVERIES IN TWO-ECHELON DIVERGENT INVENTORY SYSTEMS

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We study a divergent two-echelon inventory system consisting of one central warehouse and N retailers facing independent Poisson demand. All stockpoints use continuous review installation stock (R,Q) replenishment policies, complete backordering and FCFS allocation. Under these conditions, situations can occur when the central warehouse does not have enough stock available to cover an entire retailer order. In these situations, a choice has to be made between shipping the available part of the order as soon as possible (partial delivery) or waiting until the entire order is available (complete delivery). In previous research on distribution systems the focus has been on analyzing systems using partial deliveries, disregarding the economical (and environmental) effects of splitting orders. We introduce a handling cost which includes the extra costs occurring when an order is split (e.g. the extra cost of administration, handling, picking, loading, shipping and receiving).

We present a decision rule where partial or complete delivery is chosen dynamically for each retailer order, such that expected future costs are minimized. We provide an exact cost analysis and method for optimizing reorder points at all locations, under our decision rule. The suggested policy has a performance guarantee compared to static partial and complete delivery policies.

Keywords: continuous review, multi-echelon, batch ordering, delivery policies, Poisson demand

Special session: Inventory and the Environment

OPTIMAL LOT SIZING FOR A PRODUCTION-RECOVERY SYSTEM WITH TIME VARYING DEMAND OVER FINITE PLANNING HORIZON

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One of the important problems in inventory control is that of managing stocks in a recovering system. In such systems, customers return used products to the manufacturer for reuse. Factors such as environmental concern, legislation for waste disposal and economical benefits, motivate manufacturers to take back products after customer use. The collector may be the manufacturer himself or other companies in the business chain or companies outside the business chain. At the collection point, used products are inspected, their quality is assessed, and a decision is made on the further processing they will undergo i.e. repair, remanufacturing, recycling, refurbishing and disposal.

In this paper a recovery inventory system in which product remanufacturing is done by the original equipment manufacturer is considered. In an environmental perspective, remanufacturing can, in many cases, offer superior material recovery due to additional reused resources. The remanufacturing process brings used products up to quality standards that are as rigorous as those of new products. The planning horizon is finite and the demand rate is time varying. For satisfying the demand, there are two options: either new items are produced or the used items are repaired back to an "as new" condition, before being sold again. The returned products are a fraction of the demand and they are stored in the recoverable stocking point (recoverable inventory). At the beginning of the planning horizon the demand is satisfied by production lots of unequal size. When the production stops the demand is satisfied by remanufacturing lots of unequal size (used products are recovered by a fixed rate). The aim of this study is the determination of produced and repaired quantities which minimize the total cost over the planning horizon. This determination requires the finding of the optimal switching time from the production to the remanufacturing (an important decision key factor to improve environmental performance), the number of manufacturing and remanufacturing lots, the optimal stopping and restarting production times and the optimal stopping and restarting remanufacturing times. A procedure to find the optimal inventory policy as well as some numerical results are presented and discussed.

Keywords: lot sizing; remanufacturing; inventory; finite planning horizon; time-varying demand

A SUSTAINABLE ECONOMIC ORDER QUANTITY MODEL WITH CARBON FOOTPRINT

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A number of papers investigate carbon emission of firms in the EOQ context. These papers introduce transportation costs (Bonney, Jaber (2011), Wahab et al. (2011)), restrictions (Hua et al. (2011), Anutariya), or price discount-type limitations (Bouchery et al. (2011)) in the model in order to identify carbon sensitive costs.

Our paper contributes to the research line followed by the above mentioned previous works. We attempt to classify the most important types of activities leading to carbon emissions, and build them into the model as endogenous factors. We analyze the effects of introducing carbon emission in the model as endogenous variable by employing comparative static analysis.

Our results suggest that carbon costs may significantly modify the EOQ ordering policy. We provide estimations on the difference in EOQ with and without built in carbon costs.

Keywords: EOQ, optimization, carbon footprint, environment

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SUSTAINABLE SUPPLIER SELECTION AND EVALUATION USING DEA-TYPE COMPOSITE INDICATORS

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Based on literature results our paper examines the extension of the vendor evaluation methods with environmental, green issues. This generalization means an extension of the traditional criteria and weight system of the supplier evaluation methods.

As green issues are getting recognition in purchasing and supply management, the literature is rapidly growing on how to develop green supplier evaluation systems. Studies focus on evaluation criteria and on evaluation methods. The paper will focus on evaluation methodology, which receives substantial attention in literature: several assessment methods were developed to incorporate green aspects in supplier management decisions. However, it is still the weighted point's method, which is mostly used by practitioners.

In our paper the method of Data Envelope Analysis (DEA) is used to study the extension of traditional supplier selection methods with environmental factors. The selection of the weight system can control the result of the selection process. Our goal is to choose such weights which affect the results of the selection process. In this method we divide the criteria in two manners: the traditional and environmental (green) factors. In our presentation we combine the method of DEA with the composite indicators. Composite indicators use a very special multi-criteria decision making technique.

Keywords: green supplier assessment, DEA, multi-criteria decision making, composite indicators

CO_2 REDUCING VRP ALGORITHM DEVELOPMENT BY ACO

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The reducing CO_2 emission problem comes to be very crucial topic in distribution planning. CO_2 emission rate of truck transportation is very huge in comparison with that of railway or that of ship. Then Japanese Government asks business to introduce Modal-shift in transportation. However business cannot accept it, because the changing carrier from truck to ship or railway makes time-delay in distribution due to the few railway or ship opportunities. Practically, instead of Modal-shift, we have to concentrate on reducing attempts of CO_2 emission by the truck transportation occupies almost 100% of near distance (within 100Km) transportation. According to the formula of CO_2 emission quantity in truck transportation, which is given by the MLIT (Ministry of Land, Infrastructure, Transport, Tourism), the amount of CO_2 emission is described by the loading rate and size of the truck. Current VRP programs have not included this idea yet. Hence we develop an algorithm including this formula with aiming at both decreasing CO_2 emission and transportation distance with using ACO heuristics. Numeric experiments demonstrate the developed algorithm can minimize the total cost consisted by the transportation cost and CO_2 emission cost.

IMPACT OF LEARNING ON THE ENVIRONMENTAL PERFORMANCE OF A TWO LEVEL SUPPLY CHAIN

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The current rise in global warming is making consumers and producers more and more concerned about controlling emission and protecting the environment. There is an increasing awareness in the contemporary supply chains to include carbon reduction in their supply chain strategies [1]. That is, the supply chains are focusing on their environmental performance in addition to competing in cost and service.

The emissions that we are concerned about are mostly caused by carbon based gases such as carbon dioxide. The total amount of carbon that a firm is releasing is known as its carbon footprint. These gases are released by power plants, transportation vehicles as well as manufacturing processes. On the other hand, there is not enough number of trees and plants to soak the same amount of carbon which results in the overall climate change.

El Saadany*et al.* [2] have recently provided a mathematical decision model to account for the environmental performance of a supply chain. They developed a method to quantify a number of environmental quality functions and incorporated it into a supply chain coordination model.

The literature on supply chain management has mostly assumed the quality (or fraction of defectives) to be perfect which is far from the situations in the real world. Salameh and Jaber [4] extended the basic EOQ model for the case where each lot contains a random fraction of defective items. The fraction of defective items was assumed to have a known probability distribution. Each lot would go through complete screening and the defective items were all separated and sold at a discounted price in each cycle. This model has got noticeable attention recently. Jaber*et al.* [3] extended the model of Salameh and Jaber [4] for the case where suppliers' quality would improve by virtue of learning.

In this paper, an extension to the work of El Saadany*et al.* [2]is presented to account for the coordination of a vendor and buyer. It is assumed that vendor's cost of quality is composed of several environmental factors. This quality improves in every subsequent cycle by learning. Besides, the buyer is assumed to treat this lot following the assumptions in Salameh and Jaber [4].

An analytical model will be developed to depict the scenario and the results would be compared to those of El Saadany*et al.* [2]. An immediate extension to this work would be to incorporate Type I and Type II errors in buyer's screening process.

Keywords: supply chains, learning, environmental performance, emission, carbon footprint

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INVENTORY MANAGEMENT AND CORPORATE SOCIAL RESPONSIBILITY STANDARDS IN A DISTRIBUTION COMPANY

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Objectives of study: This paper aims to investigate the relationship between inventory management in a company and actual important concept of Corporate Social Responsibility (CSR). The paper intends to answer the question of how the most important stakeholders of a company influence the main decisions connected to inventory and in what way these decisions are related to the core subjects and issues of the general standards of social responsibility of business.

Materials and methods: The main framework of CSR has been based on the standard of ISO 26000. A qualitative case study methodology is used, interviewing managers from the Polish distributor. Inventory management is investigated according to the main principles of social responsibility, as stated in the standard.

The paper intends to answer the following research questions:

- RQ1: Does inventory management process properly aligned with distribution company's business strategy automatically allow to conform to CSR rules?
- RQ2: Are different distribution channels of a single company associated with various levels of social responsibility connected to inventory management?
- RQ3: What extra efforts in inventory management in a distribution company would be required for more complex implementation of social responsibility core subjects?

Results: The preliminary results show an example of good practice in the area of corporate social responsibility in the examined distribution company, influencing the whole supply chain. At the same time, the research paper provides some insight into such a holistic approach in which the more balanced power between stakeholders allows to arrive to better alignment of inventory management and social responsibility. According to the knowledge of the author of the paper such aspects have not been widely discussed in literature yet.

Conclusions: In this paper we would like to demonstrate that CSR in logistics and supply chain, however closely connected to sustainability issues, does not denote just environmental issues but also include governance and social issues. Considering the scarcity of work examining empirically the relations of corporate social responsibility and inventory in distribution channels, this study demonstrates the evidence of some fixed rules in that area.

Research results might be of importance for decision makers and managers in supply chains indicating which aspects of inventory management are of special significance for successful achievement of CSR goals in companies. It could help them to understand complex relationships in the CSR concept.

Keywords: corporate social responsibility, inventory management, distribution channels

SIMULATING THE IMPACT OF ENVIRONMENTAL FACTORS ON THE EXTENDED MRP MODEL

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The MRP Theory, widely researched by Grubbström, at his Linköping Institute of Production Economics and many other researchers, proved to be very usable for describing and solving production problems. The Theory was recently extended in such a way that it covers complete supply chain, including reverse logistics. We shall name it Extended MRP model (EMRP). Extended model gives theoretically appropriate tool for finding right balance between waste and reused items. Environmental taxation and energy are the main ecological parameters of the model. According to production functions the quantity of input energy is determining the optimal return rate. On the other hand, high energy prices can drastically influence the profitability of the system, which is observed through Net Present Value (NPV). The objective of this study is to test our previously presented model using simulations, and to show that simulations can be useful for observation of environmental issues in such a complex model.

NPV of revenues of the system can be calculated as $\mathrm{NPV}_{\mathrm{revenues}} = \mathbf{p}\left(\breve{\mathbf{G}}(\rho) - \breve{\mathbf{H}}(\rho)\right)\tilde{\mathbf{P}}(\rho)$ where $\breve{\mathbf{H}}(\rho)$ and $\breve{\mathbf{G}}(\rho)$ are generalized input and output matrices, $\mathbf{p}$ is price vector and $\tilde{\mathbf{P}}(\rho)$ production plan. $\breve{\mathbf{H}}(\rho)$ and $\breve{\mathbf{G}}(\rho)$ hold technical coefficients together with lead times. From environmental perspective coefficients in sub-matrix $\breve{\mathbf{G}}_{14}(s)$, which represent recycled elements for next production cycle, and coefficients in sub-matrix $\breve{\mathbf{G}}_{44}(s)$, which denote waste elements as an output of the system, are important. Return rate depends directly on production function which uses energy as one of the inputs. Reverse logistics processes are usually energy-consuming. Higher inputs of energy will increase return rates and also energy costs, which can be written as $\mathrm{NPV}_{\mathrm{energy\ costs}} = \mathbf{U}^{\mathrm{T}}\left(\breve{\mathbf{E}}_H(\rho) - \breve{\mathbf{E}}_G(\rho)\right)\tilde{\mathbf{P}}(\rho)$, where $\breve{\mathbf{E}}_H(\rho)$ and $\breve{\mathbf{E}}_G(\rho)$ are generalized input and output energy matrices and $\mathbf{U}^{\mathrm{T}}$ is row vector of unit values. $\breve{\mathbf{E}}_G(\rho)$ describes environmentally important reuse of the energy. Reuse of the energy can be subsidized and usually has positive affect to NPV of the system. The balance between environmental and business aspects of whole supply chain can be manipulated with environmental taxation on certain levels which is covered inside the price vector $\mathbf{p}$. Since such extended models are very complex, simulations can be useful tool for finding sustainable balance.

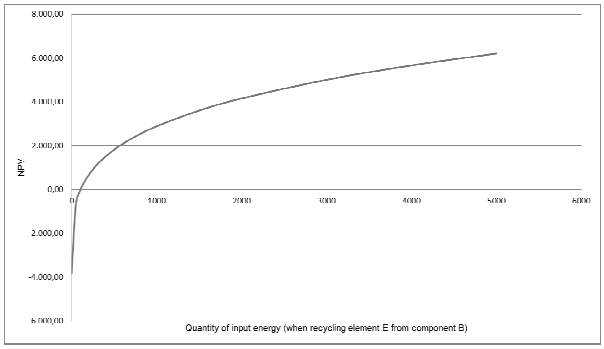

Figure 1: Increasing the quantity of input energy in recycling process of element E from component B is leading to higher NPV of the system.

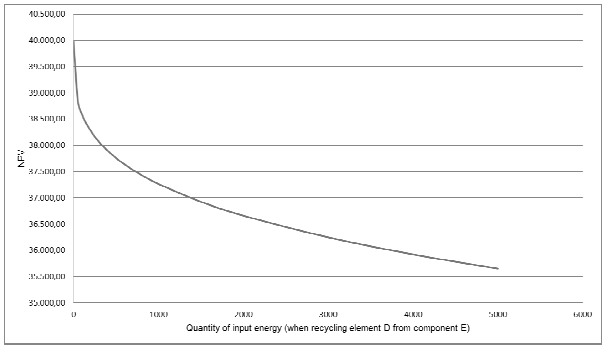

Figure 2: Increasing the quantity of input energy in recycling process of element D from component E is leading to higher NPV of the system.

As it can be seen from Figures 1 and 2, increase of the quantity of input energy into recycling sub-system does not necessarily increase overall NPV of the system. High energy prices at different activity cells and low efficiency could make recycling economically unattractive. The result will be high quantities of waste and pollution. Balance can be established using appropriate taxation. Paper will discuss the behavior of the system under the change of individual parameters. It will be shown that EMRP Theory gives answers to certain environmental questions, which can be easier observed and interpreted using simulations of the model.

Keywords: simulations, MRP theory, EMRP, supply chain, energy, environment

TACTICAL DECISION MAKING FOR DESIGNING GREEN LOGISTICS NETWORKS

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The design and operations of environmental friendly supply chains has emerged as an issue of critical importance for both academicians and practitioners. Supply chain network design principles have to be reconsidered when 'green' parameters are taken into account. This paper compares alternative supply chain networks realizations by studying optimal cost and environmental performance, in terms of CO_2 emissions, under specific inventory control policies. Specifically, three alternative logistics network design options are examined that supply a number of retail stores grouped in regions.

The paper analyzes the case of two regions, although the results can be easily expanded in the case of more regions. In the first network option, the regions are served by one central distribution centre while in the second; each region is served by its own distribution centre. Finally, the third option is similar to the second one with the difference that the second distribution centre operates as a satellite of the first one. Both the retail stores and the distribution centers employ periodic review inventory policies with the period being a decision variable. The systems performance is assessed by two objective functions. The first one minimizes the expected total logistics costs consisting of the holding costs at both retail stores and central/satellite distribution centers, the backorder costs at the retail stores and satellite distribution centre, the transportation costs, and the central/satellite distribution centre(s) leasing costs. The second one minimizes the expected total CO_2 emissions from all transportation and distribution centre operations.We implement the proposed model on the real-world case of the market of Greece.

The results indicate that the company can minimize its expected total logistics costs and CO_2 emissions by adopting the second logistics network design option. To be more specific, and if the company goes from the first to the second option, it will achieve a 5.6% reduction in its expected total logistics costs and a 48% reduction in its expected total CO_2 emissions. Finally, and if the company goes from the third to the second option, its expected total logistics costs will be reduced by 2.6% while its expected total CO_2 emissions by 18.7%.

Keywords: inventory control, CO_2 emissions, environment, supply chain, green

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Investing in knowledge society through the European Social Fund.

OPTIMAL TWO-STAGE ORDERING POLICY WITH INFORMATION UPDATE AND CARBON EMISSIONS

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Typically, ordering decisions are merely based on economic performance measures, such as profit and customer service. In recent years, however, environmental criteria have become important as well due to the increasing awareness of sustainable economic activities.

Several studies on inventory management, concerning carbon emissions, examine a situation in which a retailer can procure a certain good from two supply sources differing in lead time and purchasing price. As the offshore source is located distant from the market, the transport of ordered goods is necessary and causes carbon emissions. Therefore, the retailer's decision on how much to order from that source has to comply with an environmental regulation, which affects the possible quantity procured as well as the profit. It is assumed that no transport emissions arise when the retailer orders from the onshore source. In the known models the first order is placed with the offshore supplier before the start of the selling season and demand is stochastic. The second order is placed under certainty with the onshore supplier during the selling season, assuming that demand has already been realised. Referring to seasonal products this assumption often is not satisfied. Even though a retailer can obtain additional information on product demand over time, in most cases it is not possible to exactly determine the market demand.

The purpose of this research is to modify the existing approaches mentioned above by considering a situation in which a retailer faces stochastic demand when ordering from both sources and has to meet environmental regulations at the same time.

In the present study a retailer can improve its forecast by using market signals observed after placing the first order. This information is used to adjust knowledge of product demand and to decide on how much to order from the onshore source at the second stage. The information update is modelled by using the Bayesian approach. Moreover, the regulation of transport carbon emissions is based on an emission trading scheme under which firms receive a limited number of emission allowances free of charge. If a company produces more emissions than covered by its certificates, it has to buy additional allowances. In the opposite case, it is able to sell the remaining allowances and thereby generates revenue.

As a result of the study a model based on the newsvendor framework is developed that includes the procurement of a single product from two supply sources under uncertainty as well as environmental issues.

IMPACT OF TRANSPORTATION LEAD-TIME VARIABILITY ON THE ECONOMICAL AND ENVIRONMENTAL PERFORMANCE OF INVENTORY SYSTEMS

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Goods transportation is a major cause of CO_2 emissions and is cited as the single largest source of environmental hazard in the logistics chain. In order to decrease the negative environmental impact of goods transportation, different entities of the logistics chain can take on actions with immediate implications on the transportation system. For example, manufacturers and retailers can use more environmentally friendly transportation modes, or reduce the need for transportation by working with on-shore suppliers as well as centralizing warehouses. On the other hand, logistics providers can work on reducing the carbon intensity of the energy they use and increase the energy efficiency of their operations by freight consolidation or by improving the technical features and the maintenance of their vehicles. Additionally, there are actions which can help improve the system through the interaction of the overall operations. One example is coordinating production schedules among suppliers to allow joint shipments which results in better vehicle utilization and hence fewer emissions.

Similarly, in this paper we analyse the economical and environmental implications of a serial connected inventory system through such an interaction effect: the indirect effect of transport lead-time variability through the replenishment policy on economical and environmental performance of supply chains. We consider a shipper, i.e. a manufacturer or a retailer who works with overseas suppliers and replenishes based on standard inventory control policies using ocean freight for regular replenishments and air freight in case of shortages. It is commonly acknowledged that unanticipated variability in demand and/or lead-time is the major reason for stock-outs or excess inventories in supply chains. As the ocean carrier is able to reduce the lead-time variability under certain conditions, the need for both emergency shipments by air freight as well as safety stocks will decrease, which will also have significant impacts on the environmental performance of the supply chain. In order to quantify the effect of lead-time variability reduction on carbon emissions and performance, we present and analyse a model based on standard multi period inventory control policies in such a dual transportation mode setting. We illustrate our findings and conduct a sensitivity analysis using a simulation study.

Keywords: inventory, transportation, lead-time uncertainty, carbon emission, simulation

AN INVENTORY AND SOURCING DECISIONS MODEL WITH A TEMPORARY PRICE DISCOUNT FOR IMPROVED SUSTAINABILITY IN FOOD SUPPLY CHAINS

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Greening is now widely acknowledged as a potential source of competitive advantage and a demonstration of social responsibility. Therefore, the assessment of the whole supply chain should now be integrated with environmental criteria. For inventory management, this means that the focus has to shift from merely minimizing inventory costs, to carefully balance with wastage and carbon footprint.

Taking the food supply chain as an example, a large amount of energy is needed for the temperature controlling process during manufacturing, storage and transport, in an attempt to reduce the amount of wastage generated by reason of food perishable nature along the network flow. When looking from supermarkets perspective, a discount pricing policy is a common practice used in enhancing sales of items close to their best-before dates and reducing loss from wastage. As it appears, choices of suppliers in the system, supplier selection and order allocation processes with regard to the environmental aspect are used here.

Therefore, this paper introduces a model to determine inventory and sourcing decisions in multiple-tier supply chains, in particular a food chain, with the aims of minimizing total cost invested, wastes from unqualified items and carbon emissions generated together with a consideration on the effects of temporary discount sale. Food quality degradation is integrated in the resulting model for the purpose of product quality control throughout the food supply chain. The model is stated as the optimization problem which is solved by a multi-objective mixed integer linear programming method. The model and solution method is illustrated on an example problem.

Keywords: green food supply chain, inventory, sourcing decisions, price discount, multi-echelon

Special session: Service Logistics

SERVICE ENGINEERS CAPACITY PLANNING FOR THE FULFILLMENTOF DIFFERENT TYPES OF SERVICE LEVEL AGREEMENT

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Nowadays, most of the customers require a service contract when they buy an advanced capital good from a supplier. In these contracts, the supplier and the customer mutually agreeon a predeterminedservice level. A service level agreements (SLAs) can be, for example, a minimal/average system availability, a maximal time between failure notification and failure fix, or a maximal time between failure notification and on site field technician arrival. After sales business is not only a new requirement from the market but also a considerable source of revenues for suppliers and manufacturers. To reach the agreed upon SLA, a supplier needs to efficiently organize its spare parts network and has enough field Service Engineers (SEs) ready to be dispatched on the missions to fix the failures reported by customers. The problem of SEs crew dimensioning and schedulinggot a little attention in the scientific literature. We recently observed that at Océ, a leading printings solutionprovider in The Netherlands, a large part of the logistical delay is due to the unavailability of an SEon a failure notification. In other words, there is a considerable queueing delay before an SE becomes available for a call to fixreported by a customer. This is mainly due to the high SEs utilization. Clearly, a supplier needs to differentiate between customers and to give priority for those with a strict SLAs. This also contributes to the delay increase especially for those customers with low priority.

Our objective in this paper is to optimally dimension the FEs crew to satisfy the different requirements of the customers. This will be done under the assumption that the FEs scheduling gives a high priority for customers with a strict SLAs and an FE mission cannot be preempted.To solve this problem we will use the framework of queueing theory. Especially, we will consider a multi-server, multi-class queuewith a nonpreemptive priority discipline. In this queue, the multiple servers represent the multiple FEs in a region. The arrival process to the queue represents the failure notifications from the customers which assumed to be a Poisson process. The service time represents the time for an FE to arrive to the customer's site and to fix the failure which is arbitrary distributed. We note that we are not just interested in the mean waiting times for an FE but also its distribution. This is because our target service level can be an average or a maximum FE on site response time. Since this problem is known to be complicated to be solved exactly we shall use an efficient analytical approximation. Preliminary results show that a huge variations in the waiting time of low priority customers classes are observed in case of an improper FEs crew dimensioning.

Keywords: service logistics, service engineers dimensioning, queueing system, analytical approximation

SERVICE DIFFERENTIATION THROUGH SELECTIVE LATERAL TRANSSHIPMENTS

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Increasingly, suppliers of capital goods – such as medical systems or power plants–offer their customers performance-based service contracts for system upkeep. The performance agreements in such contracts, such as a maximum response time in case of failure, may differ greatly among customers to reflect their perceived value of system availability. Suppliers therefore face the challenge of providing all customers with adequate service from a single service organization.In this paper, we focus on service differentiation when supplying spare parts.

A common approach in literature is the use of so-called *critical level* policies, where stock is reserved for premium customers once the inventory level drops below a certain threshold. Such policies tend to have practical drawbacks, such as a lack of acceptance from both customers with regular contracts and employees who handle spare parts requests. Therefore, alternatives need to be considered. In this paper, we propose the use of*selective lateral transshipments* focused on waiting time reduction for premium customers. That is, warehouse stock is used to meet demands from all types of customers. However, if a warehouse does not have parts in stock, it can meet demands from premium customers by using stock at other warehouses at the same echelon level (i.e. a lateral transshipment). As transshipments are relatively expensive, this option is not used for non-premium customers.

We consider a multi-item model with two customer classes and multiple warehouses, with the objective to minimize system costs while meeting the customer-specific service requirements at each warehouse. Using continuous-time Markov chains, we are able to analyze the system for given values of decision variables (e.g. stock levels). Furthermore, we show how to find near-optimal stock levelsusing an approach based on Dantzig-Wolfe decomposition. An important aspect of our approach is the intelligent selection of item polices to be included in the multi-item optimization in order to keep computation times within reasonable limits. In an extensive numerical experiment, we verify the added value of using selective transshipments by comparing it to alternative approaches, such as one-size-fits-all approaches and critical level policies.

Keywords: spare parts, inventory, service differentiation, lateral transshipments, Markov chains

OPTIMAL AND HEURISTIC REPAIRABLE STOCKING AND EXPEDITING POLICIES IN A FLUCTUATING DEMAND ENVIRONMENT

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We consider a repairable item inventory system consisting of one stock-point. The repairable item is a critical component for a fleet of technical systems such as trains, planes or manufacturing equipment. A number of spare repairables is purchased at the same time as the technical systems they support. Demand for repairable items is a Markov modulated Poisson process. Backorders occur when demand for a ready-for-use part cannot be fulfilled immediately. Since backorders render a system unavailable for use, there is penalty per backorder per unit time. Upon failure, defective parts are sent to a repair shop that offers the possibility of expediting repair. Expedited repairs have shorter lead-times than regular repairs but are also more costly. Managers of the system described above make two important decisions: How many spare repairables to purchase en when to expedite repair. We formulate the decision to use regular or expedited repair as a Markov decision process and characterize the optimal repair expediting policy for the infinite horizon average and discounted cost criteria. We find that the optimal policy may take two forms. The first form is simply to never expedite repair. The second form is a type of threshold policy. We provide closed form necessary and sufficient conditions that determine what form is optimal for any given instance. We also show how to find the optimal joint repairable stocking and expediting policy and propose a heuristic policy. In a numerical study, we show that our heuristic performs very close to optimal with an optimality gap below 0.76% for all instances in our test bed and that it also outperforms other more naive heuristics.

Keywords: expediting, Markov decision process, optimal policies, heuristic policies

AN IMPROVED DECISION RULE FOR EMERGENCY REPLENISHMENTS

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This paper provides a new decision rule for emergency replenishments in an inventory system. The decision rule is a generalization of a previous decision rule suggested and evaluated in Axsäter (2003, 2007). An Improvement step is added to this rule and this often means considerably better performance. The decisions are based on complete information about the system state. An advantage with our decision rule is its generality. It is possible to handle batch ordering, compound Poisson demand and emergency replenishments that take time. The decision rule has also a performance guarantee in the sense that emergency replenishments will always lead to lower expected costs. The rule can also be used in connection with lateral transshipments.

Keywords: inventory; stochastic; emergency transshipments; lateral transshipments

LAST TIME BUY AND RE-USE OF SPARES FOR ADVANCED CAPITAL GOODS

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Background: Uptime is an important performance indicator for advanced capital goods like high tech manufacturing equipment, computer systems and medical systems. To minimize downtime, such equipment is typically maintained by switching failed parts by spares. Spare part inventory availability is thus a critical issue. Because the life cycles of these capital goods are typically long (say 5-30 years), spare parts are typically not manufactured anymore at a certain point in the life cycle, simply because it is not profitable for the supplier. Spare part availability throughout the remaining service period (which can be many years) should still be guaranteed. This is often done using a large investment in spares when manufacturing is discontinued (the *last time buy*). We have observed in practice that this typically leads to high obsolescence at the end of the service period. To reduce obsolescence cost while avoiding out-of-stock situations, we may use other sources for spare part supply like repair of failed parts, retrieving parts from complete systems that are dismantled and redesign of parts. In this paper, we focus on repair of failed parts that are returned from the field and whose supply is thus correlated to the demand in preceding periods.

Objectives: We focus on finding the optimal Last Time Buy order quantity in combination with an optimal repair policy for failed parts returned from the field. We balance the various cost factors, such as holding costs, repair costs, shortage cost during the service period and obsolescence cost at the end of this period. We include variable lead times for both the return of parts from the field and the repair times. Also, we account for the fact that only a fraction of parts will be returned from the field, and only a fraction of the repairs is successful. This yields a new combination of model aspects that is practically relevant and has not been considered before in the literature.

Methods and results: We develop an exact method for slow movers based on stochastic dynamic programming, and use the insights from this model to develop heuristics for extended models, in particular for fast movers. We see that, under certain conditions, the release of repair orders follows a dynamic order-up-to level policy with order-up-to levels depending on the stage in the remaining service period. We exploit this finding to develop heuristics for a broader range of models, including fast movers. In a numerical experiment, we study the sensitivity of our solution to changes in the key parameters like repair lead-time, repair yield rate, return lead time and return yield. Also, we apply our approach to a case study in industry.

Keywords: spare parts, inventories, last time buy, repair, dynamic programming

INVESTMENT DECISIONS IN COLLECTIONS FOR RENTAL COMPANIES UNDER CUSTOMER CHOICE BEHAVIOR

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Customer service is being recognized as the key factor in current competitive business environments in attracting and maintaining customers. Key performance measures include availability and accessibility. In case there is a stock out, the customer needs to be served with an alternative. Extensive studies in retail reveal that only 15% of the customers who observe a stock out will wait for the product to be on the shelves again, whereas the remaining 85% will either buy a different product (45%), visit another store (31%) or do not buy any product at all (9%). The objective of our paper is to study assortment decisions while addressing all types of consumer choices in case of stock outs.

In particular, we focus on public libraries. They need to balance a highly varied assortment with the risk of customers not getting the exact title they had in mind. If a title is not available, the customer could take a different title from the same library as substitute, visit a different library (i.e., an emergency lateral transshipment), make a reservation or leave empty handed. These different behaviors influence the stock levels of the titles on the shelves at the different locations and ultimately the customer satisfaction. We design tools to make long-term strategical decisions which and how many products to include in the permanent assortment of each branch.

One of the distinguishing characteristics of the inventory model for libraries that sets them apart from other models, where customer behavior during a stock out is taken in account to some degree, is that all books are returned after some time. We model the inventory system as a continuous review replenishment policy with base-stock levels where an ordered item is delivered after a stochastic lead time. We propose a general customer choice model where a probability is assigned to each alternative in case of a stock out. When we assume that customers arrive according to a Poisson process, the system can be approximated by a queuing network with no buffers and flows of redirected customers to substitutable items and locations. Similar inventory models seem to be suitable for spare parts inventory management with substitution.

A case study demonstrates that our heuristic procedure is effective to define and control the assortment variety at libraries. Our approximation model finds a collection with an average item fill rate of 55% compared to 30% in the current situation while the size of the collections is kept equal.

Keywords: assortment planning, customer behavior, stock out, substitution, lateral transshipments

JOINT OPTIMIZATION OF MAINTENANCE AND SPARE PARTS: THE VALUE OF PLANNABILITY

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Age-based replacement has been shown to be superior to block replacement as in age replacement items are replaced at critical ages rather than at prescribed times (see Berg 1976). Yet this proof did not consider the consequences of an age-based policy for the resulting spare parts supply chain. Moreover, in multiple item age replacement, age-based replacement will lead to quite a diversity in the moments items will be replaced. In block replacement, where items are replaced at fixed time intervals, it is much easier to achieve a joint replacement time and a coordination with the ordering of spare parts. The question now is under which conditions the joint optimization of maintenance and spare parts control will be best under block replacement type policies.

To investigate the problem we consider n identical components each with a Weibull distributed lifetime distribution and for which both cost of failure and preventive replacement are given. Next we assume spare parts inventory holding costs. We exclude economies of scale for replacement, as that can easily be incorporated and would favour the block replacement over age replacement. The replacement policy states when components should be replaced when enough spare parts are available. If these are not, then an emergency order is placed and the components are replaced when the replacement parts come in. Upon failure components are replaced if a spare is available. If not we incur a downtime cost per time unit. Next to block replacement we also consider modified block replacement which skips a replacement if its age is below a threshold, but which sticks to the intervals. For the spare parts ordering we consider both regular ordering and emergency ordering at a higher price (per item). The spare parts inventory control is based on a (s,S) policy with separate ordering for the items needed in the block replacement.

As the problem is very complex we have to use simulation to evaluate the average costs for each policy. Next we consider both optimisation of the replacement interval as well the optimisation of the base stock level.

The results confirm that age replacement outperforms both modified and standard block replacement in terms of maintenance costs. Yet if we also consider the ordering and inventory holding costs then the modified block replacement policy together with separate ordering yields the lowest overall costs.

Keywords: spare parts inventory control, age replacement, block replacement, joint optimization

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M. Berg (1976), A Proof of Optimality for Age Replacement Policies, J. of Applied Probability, 13(4), 751-759.

AN EMPIRICAL STUDY ON REPAIR SHOP CONTROL IN MAINTENANCE SPARE PART ENVIRONMENTS

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This paper presents the specific control characteristics of repair shops in maintenance spare parts environments. The physical layout of repair shops has many similarities with traditional job shops, however, empirical evidence shows that the required control of repair shops is different on several characteristics.In-depth case studies are carried out at six different companies that maintain high value capital assets that they need to deliver their products and services. It is concluded that to approach repair shop control in maintenance spare parts environments, a dedicated framework is necessary. The control characteristics as described in this paper will be part of this framework.

Keywords: production control, repair shop control, maintenance spare parts planning and control

RISK POOLING IN SERVICE LOGISTICS

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In service logistics, OEMs or life-cycle product support service providers are often required to make decisions based on sparse data. This is due to the low-frequency failures of highly reliable equipment. As a result, most OEMs or service providers face tremendous challenges in attempting to achieve the contractual service levels, both in the initial phase when historical data is not available and during service contract execution. This paper contributes to the existing research in two respects:

- We distinguish aleatory uncertainties (due to stochastic failure processes) from epistemic uncertainties (due to imprecise knowledge of the failure processes).

- We show that the contractual service level could be jeopardized by ignoring epistemic uncertainties in the decision making process. However, this adverse effect can be eased by risk pooling and an efficient use of the available information.

We first study the service performance (service level and cost) under aleatory uncertainties only. In this situation the parameter of the failure process is assumed given. To model the reality of imprecise knowledge of the stochastic process we then assume that only the distribution of the parameters is given. We compare these two scenarios by calculating the expected shortfall in contractual service levels when decisions are made without taking epistemic uncertainties into account.

We than study the risk pooling effects on the expected shortfall in both initial phase and contract execution phase. We employ Bayesian inference to update our state of knowledge using operations data during the contact execution phase.

Our numerical experiments show that the expected shortfall can be reduced by pooling risks.

We applied our method in a case study at Fokker Services B.V., a performance-based aircraft maintenance, repair and overhaul (MRO) service provider. Our results are very promising and are supported by engineers' and experts' opinions.

Keyword: risk pooling, performance-based logistics, aviation application, aleatory uncertainty, epistemic uncertainty

A SIMULATED ANNEALING APPROACH FOR CAPACITATED ORDER PICKER ROUTING IN A WAREHOUSE

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This paper studies the order batching and routing problem of order pickers in conventional multiparallel-aisle picker-to-part order-picking systems. Manual order picking is known as the major cost component in warehousing, so reducing the travel time – and consequently the travel distance – is a primary objective in warehouse optimization. This paper analyses order batching and routing in an order picking system with a new capacity constraint of total item weight. We present several heuristics for batching orders and routing order pickers in a rectangular warehouse and combine them with a Simulated Annealing approach to improve the resulting order batches in order to minimize the total travel time. The proposed methods are compared and evaluated in an extensive numerical study for a given set of orders and a given storage assignment. It is demonstrated that the developed approach provides a solution for improving order batching and order picking efficiency.

Keywords: order-picking, routing, warehouse, warehouse optimization, simulated annealing, picker-to-part systems, storage, heuristics

JOINT PRICING AND INVENTORY DECISIONS WITH DELAY SENSITIVE CUSTOMERS

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In this talk we consider joint pricing and inventory decisions in a capacity constrained service system. There are M types of customers, each type arriving to a service system according to its respective Poisson process. Upon arrival, each customer demandsan item, for instance a spare part to be used for a replacement. If the item is on-hand available, then the arriving customer does not wait, whereas if the item is not available, the customer waits until the item is delivered through a possibly capacitated system. Customer types are differentiated using priorities and the waiting times of the customers for delivery depend on the priority of the type. The service system operates under an order-up-to policy and decides on the price to be charged for each customer type, and the order-up-to level for the spare parts inventory. Customers, on the other hand, decides on joining the system or not, based on their reservation price, waiting cost, and the price charged for the item. In equilibrium, the arrival rate of a customer class is such that the reservation price of the customer is equal to the sum of the price for the spare part plus the waiting cost. Based on the equilibrium arrival rates of customer types, the service system collects revenues and incurs inventory holding costs. The objective is to maximize the expected profit of the service system by choosing the best set of prices (for each type) and the best order-up-to level. Our first resultprovesthe form of the priority assignment policy. We show that customersare assigned priorities based on an ordering of the unit waiting costs of customer types. Then, we present a near explicit solution for the optimal order-up-to level, and provide conditions for obtaining the optimal price set. Finally, we show that the optimal prices are incentive compatible. That is, the price set obtained maximizes the expected profit of the service provider even if the service provider does not have information on the type of an arriving customer. Providing a menu of prices and corresponding priorities, and letting the customer choose one price from the menu is sufficient. We also provide a number of illustrations of our results through numerical examples.

OPTIMUM CONTROL POLICY FOR SPARE PART INVENTORY IN EXISTENCE OF SUPPLY RISK AND SECONDARY MARKET

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In the last phase of a life cycle, the product is no longer manufactured and the original equipment manufacturers (OEM) only provide spare part support for maintenance services. However due to several factors, such as low profitability, technology obsolescence etc., this support is subject to a risk of supply failure. From the maintenance company perspective, spare part supply may stop while the demand for maintenance services and spare parts still exists in the customer side. Therefore maintenance repair organizations (MRO) should consider this risk especially for the spare parts of *out-of-production* systems due to various implications of supply loss. Furthermore, in some sectors secondary markets exist for spare part trading among different parties. Existence of such a supply alternative makes the inventory control system more complicated. On the other hand too much reliance on the secondary market may hasten the stop of the regular supplier. In this study, a recursive inventory control model is built for a system including supply failure risk and a secondary market. The effects of the secondary market and the supply failure risk on the optimum policy are analyzed using this model.

Keywords: dynamic inventory control, secondary market, supply failure risk, out-of-production systems, spare parts

SPARE PARTS INVENTORY POOLING: HOW TO SHARE THE BENEFITS?

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We consider several companies who require expensive, low-demand spare parts for their high-tech machines. They can collaborate by fully pooling their inventories of common parts, which is beneficial from the whole system's point of view. The question we pose is how the participants should distribute among themselves the collective costs of the shared inventory system in a fair way.

To study this, we consider a stock point for spare parts that is operated by multiple decision makers, each facing a Poisson demand process. The joint stock point is controlled by a continuous-review base stock policy with an optimal base stock level. Unfulfilled demands are backordered. We consider penalty costs for backorders and holding costs for stock on hand. For this model, we derive new structural properties of the resulting costs as a function of the demand rate.

We use these structural properties to prove that if total costs are allocated proportional to player's individual demand rates, then no subset of players has an incentive to split off and form a separate pooling group. That is, this proportional rule always accomplishes core allocations of an associated cooperative game. We further show that if this proportional allocation is implemented via a certain intuitive process of allocating realized costs as they materialize, then players are induced to truthfully reveal their private demand information a priori.

SPARE PARTS SHARING WITH JOINT OPTIMIZATION OF MAINTENANCE AND INVENTORY POLICIES

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We consider an industrial setting in which a number of companies operating the same technical system are willing to share expensive spare parts that are required for both failure replacement and preventive maintenance purposes. The novelty offered by ourstudy lies in the integration of maintenance and inventory policies that takes place in a collaborative setting where spare parts are shared by different companies. To the best of our knowledge, the literature to date only tackles all those aspects partially. The specific setting considered in this study consists of one 'holding' company and a number of 'participating' companies. The inventory of spare parts are pooled at the holding company who is responsible for controlling spare parts inventory in the system whereas the participating companies are given access to use the spare parts whenever a preventive maintenance or failure replacement occurs. We develop two models to analyze the problem. The first model deals with the joint optimization of maintenance and spare parts inventory policies under a centralized setting in which all decisions are made by a central decision maker. We develop a discrete-time Markov decision process formulation for both a single-company problem and a multi-company problem. The model developed is general in the sense that no restrictions have been made in relation to the choice of inventory and maintenance policies.The cost savings obtained as a result of sharing the spare parts are evaluated through numerical experiments. In the second model, the cooperating companies are considered as independent entities. Using a cooperative game framework, we propose a number of cost allocation schemes such that all the companies involved are better off by sharing the spare parts rather than acting independently.

Keywords: spare parts; maintenance; inventory sharing; cooperative game theory

DEVELOPING A SERVICE OFFERING FOR A LOGISTICAL SERVICE PROVIDER – CASE LOCAL FOOD SUPPLY CHAIN

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Local, alternative and short food supply chains have attracted considerable public and political interest in recent years. As a consequence, also academic research has started to examine the possibilities and preconditions of local food systems as an alternative food supply chain. The small-scale rural food manufacturers and distributors face a traditional logistical problem: logistics and distribution are expensive to do alone, and access to major food distribution systems is difficult. As the customers` interest and demand for local food products is growing, the needs, requirements and opportunities for logistical service providers for local food producers should be studied in order to create innovative solutions to the problem.

The first aim of this paper is to suggest a framework for developing a service offering and a business model for a logistical service provider. Secondly, the paper presents potential business models and value-adding service offerings for a logistical service provider of local food.

The regional food supply chain is studied by conducting and analyzing a total of 23 semi-structured interviews covering the whole supply chain (food producers, downstream operators and retailers) in southeastern Finland. In the data analysis, the existing logistical service requirements of different participants in the regional food supply chain are classified and compared to existing knowledge of logistical service offerings.

As a result, the paper introduces potential business models for regional logistical service providers and a framework for analyzing them. Based on the discovered service requirements and needs, the paper constructs and analyzes two possible service offerings, including the needed core services, support services and additional services. The two constructed offerings and service packages are evaluated and compared from the perspectives of different actors in the local food supply chain by their general features, operability and feasibility.

Keywords: local food supply chain, service offering, logistics service, region-based logistics, food industry

IMPROVING SERVICE PARTS INVENTORY MANAGEMENT FOR TECHNOLOGICAL PRODUCTS. A SIMULATION-BASED CASE STUDY

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The increasing importance of after sale services and service parts provision generated increased attention by OEMs that need supporting the products they sell. An efficient and effective service parts management is, indeed, a lever for improving customer satisfaction and profits. Inventory management plays a central role in achieving these goals. However, previous research suggested that the real-life application of optimization models and techniques developed by scientific literature is limited.

Therefore, this paper considers and models a real-life problem, and proposes a simulation-based solution understandable and practically implementable by company managers. We consider the case of a multi-item, two-echelon inventory system for service parts that consists of a central warehouse and a number of local warehouses. The local warehouses consist of the vans of field engineers, and are therefore subject to space constraints.

The case study concerns a company that manufactures printing systems. A regional warehouse located in Italy serves about 180 vans of field engineers located all over the country. The OEM centrally manages the stock allocation and dimensioning for all the local warehouses. An (s, S) policy is adopted, with re-order points and order-up-to level set by the analysis of historical consumption and experience. Both normal and emergency orders are allowed.

We aim to assess by the means of a simulation model the opportunity to reduce logistics costs without affecting the service level, considered satisfactory by the company. Therefore, different strategies are tested and combined: i.) modifying the set of parts to be allocated to the vans; ii.) increasing order-up-to levels of "fast movers" to reduce the number of shipments; iii.) reducing the delivery frequency and constraining the number of emergency orders.

The scenario analysis carried out suggested easily achievable improvements to the company, and provides as well conceptual insights for service parts management.

Finally, since in the simulation we adopted a single-echelon perspective (the costs at the regional warehouse are incurred by the parent company of the case company studied) we propose further developments based on a global perspective (two-echelon, information sharing and adoption of an integrated perspective at the horizontal level).

Keywords: service parts, inventory management, service level, simulation model, case study

LAST TIME BUY DECISIONS FOR PRODUCTS SOLD UNDER WARRANTY

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Many products in the consumer market are sold with a warranty that the product will be operational during a certain period.A warranty servicing strategy for these products usually consists of some decision rule when to replace and when to repair a failed product based on criteria like the age and usage of the product. Many models focus on the analysis of a single product and assume that a new product to replace a failed one is always available if needed and that replacement occurs in negligible time. However, new product versions appear quickly on the market, and therefore manufacturing of the previous version may be discontinued far before the end of the warranty period of the products in the market. To facilitate product replacement during the remaining warranty period, the supplier needs to procure a certain amount of spare products (or spare parts) at once to cover the demand during the remaining warranty period. This is called the *last time buy* decision.

The basic trade-off for the last time buy decision is between the costs of spare part unavailability versus the costs of obsolete spares at the end of the warranty period. The last time but decision interacts with the warranty servicing strategy: The decision rule when to repair or replace a product determines the demand for spare parts, whereas the availability of spare parts determines the possibility to replace a product. A complication is that spare parts are kept on stock for the complete set of products in the field, thereby taking advantage of the risk pooling effect. As a consequence, the problem is intrinsically a *multi-product* problem, whereas the analysis of a single product is typically sufficient to optimize the warranty servicing strategy given unlimited supply of replacement parts.

We study stochastic models for the joint problem of finding the last time buy quantity and the warranty servicing strategy from the manufacturer's perspective. We develop approximations and optimization heuristics, and check the accuracy of our approximations by comparison to simulation. We perform numerical experiments to get insight in the type of policies to be used.

Keywords: reliability, inventory, maintenance, warranty, spare parts, last time buy

SPARE PARTS INVENTORY CONTROL FOR AN AIRCRAFT COMPONENT REPAIR SHOP

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We study spare parts inventory control for a repair shop for aircraft components. Defect components that are removed from the aircraft are sent to such a shop for repair. Only after the component has been inspected does it become clear which specific spare parts are needed to repair it, and in what quantity they are needed. Market requirements for shop performance are reflected in fill rate requirements for the turnaround times for each component type. From a modeling perspective, the system is similar Assemble-to-Order systems. The inventory is controlled by independent (s,S) policies. We study the optimization of these policies. This problem is formulated as an integer program. We solve the LP relaxation with column generation, and develop an efficient method to solve the related pricing problem. This method is interesting in its own right because it works under more general conditions than existing methods. LP-based algorithms are developed to find integral solutions. These algorithms solve large-scale practical instances of the problem in minutes. We find that implementation of the algorithm at a repair shop improves cost efficiency, and allows for better alignment between inventory decisions and performance targets than traditional methods.

Keywords: continuous review assemble-to-order systems, (s,S) policies, spare parts, column generation, case study

RISK MANAGEMENT IN PERFORMANCE BASED LOGISTICS

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Risk management in service logistics has become an emerging area in operations research. Under Performance Based Logistics (PBL) contract, an original equipment manufacturer (OEM) or an independent service provider is required to meet contractual life-cycle product support levels regardless of the cost of doing so. Yet, because PBL is relatively new and complex, most OEMs face tremendous challenges in attempting to measure and mitigate its risks. Hence, effective risk management is critical to the success of PBL.

This paper contributes to the existing research by developing a consistent and coherent risk measure based on empirical data, and by providing a practical risk mitigation strategy for supporting post-production capital goods.

In a closed-loop supply chain of post-production capital goods with performance based contracts, OEMs or service providers are committed to provide spare parts for continued operations by component repair or procurement from secondary market. To evaluate the risks of the extreme repair costs for each critical component, we develop a consistent and coherent risk measure using the concept of Conditional Value-at-Risk (CVaR). CVaR at a certain fraction is the expected costs in the worst fraction of cases, for example, the expected costs in the top 10% expensive repairs. This fraction represents OEMs' or service providers' risk attitude, which is determined by their management strategically. Given the risk attitude, we can calculate a cost trigger point as a benchmark for extreme expensive repairs, which can be used by OEMs or service providers for make-or-buy decision making. We then calculate the Expected Extreme Repair Cost (i.e. CVaR) in its tail beyond the cost trigger point. Because of the relatively few extreme observations, we apply the Extreme Value Theorem to estimate the distribution of the extreme repair costs.

In the post-production capital goods supply chain, one can try to avoid the extreme expensive repairs by procurement from the secondary market with lower prices. However, in reactive business processes, due to the time pressure in the make-or-buy decision making and high uncertainties in the market prices, these expensive repairs can hardly be avoided. To mitigate the risks in extreme repair costs, we propose a proactive procurement strategy with purchasing limits (both prices and quantities), taking into account the Expected Extreme Repair Cost and the expected holding costs of the procurement.

We applied our results in a case study at Fokker Services B.V., a performance-based aircraft maintenance, repair and overhaul (MRO) service provider. Our risk evaluation of its repair costs and the proactive procurement strategy enables the MRO service provider to make more consistent make-or-buy decisions and to plan proactively for the risk mitigation. As a result, large cost savings have been achieved.

Keyword: risk analysis and management, aviation applications, conditional value-at-risk, extreme value theorem, proactive procurement

In Absentia

PRODUCTION-INVENTORY SYSTEM WITH FINITE PRODUCTION RATE, STOCK-DEPENDENT DEMAND, AND VARIABLE HOLDING COST

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In general, traditional production-inventory systems are based on a number of simplifying - but somewhat unrealistic - assumptions, including constant demand rate, constant holding cost, and instantaneous order replenishment. These assumptions have been individually challenged in numerous variations of production-inventory models. Finite production rate models, such as economic production quantity (EPQ) systems consider gradual order replenishment. Stock-dependent demand models assume the demand rate to be an elastic function of the inventory level. Variable holding cost models assume the holding cost per unit of the item per unit time to be a function of the time spent in storage. In this paper, the three simplifying assumptions are simultaneously relaxed in a new production-inventory system with a finite production rate, stock-level dependent demand rate, and variable holding cost. Mathematical models and optimum solution procedures, including nonlinear programming, are presented for two functional forms of holding cost variability.

Keywords: production-inventory system, stock-dependent demand, variable holding cost, nonlinear programming

TWO-PERIOD DUAL-SOURCING PRODUCTION PLANNING AND INVENTORY CONTROL MODEL WITH FORECASTS UPDATING

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We develop a single product stochastic two-period production planning and inventory control model, which combines the use of information updating with the flexibility of different delivery lead-times. The demand is modeled using two independent ran-dom variables over a two-period selling season. At the beginning of the first period two quantities are ordered using two different supply options: a local supplier who delivers the ordered quantity immediately; a second supplier who delivers the ordered quantity at the beginning of the second period. The slow supply source has lower unit ordering cost than the fast supply source. Since the model considers an initial inventory, the decision maker has the opportunity, at the beginning of the first period, to return a part of the available inventory to the supplier (or to sell it in a parallel market). At the end of the first period, any unsatisfied demand is backlogged to be satisfied in the next period. At the beginning of the second period, an exogenous market information is used to update the second period demand forecast. Using this updated demand forecast and taking into consideration the actual inventory level, the decision maker orders an additional quantity using a fast procurement source, and/or returns another quantity to the supplier (or sells it in a parallel market). At the end of the planning horizon, any remaining unit is salvaged at a salvage value, and any unsatisfied demand is satisfied by using a high cost emergency procurement source.

Via a dynamic programming approach, we exhibit the structure of the optimal policy, partially characterized by order-up-to and salvage-up-to levels. We provide the structure of the second period conditional optimal policy and some analytical insights that permits to characterize the first period optimal policy. Furthermore, through a numerical study, we exhibit the impact of the information quality on the optimal policy. More specifically, we show the impact of the available information concerning the second period demand on the trade-off between the different procurement options.

Keywords: production planning, inventory control, forecast updating, dual supply, short life-cycle products

ORGANISATIONAL BARRIERS AND ENABLERS TO VENDOR-MANAGED INVENTORY

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Both in practice as well as in literature it is widely acknowledged that companies can heavily benefit from Vendor-managed Inventory. Although different definitions exist, Vendor-managed Inventory systems are generally described as integrated inventory systems in which the supplier takes full responsibility for maintaining the inventory of a material or product at the buyer's location. In many cases a third party logistics provider is involved in the process of supplying products or materials in order to meet the required inventory levels parties have agreed upon. Despite the benefits associated with Vendor-managed Inventory, recent studies indicate however that in 25% of the cases the implementation of a Vendor-managed Inventory system has no added value at all. It is furthermore suggested that implementations meet the expectations of companies in only 30% of the cases (Claassen et al, 2008).

Many of the studies on Vendor-managed Inventory systems focus on the technical aspects of these systems (e.g. (Szmerekovsky e.a., 2008; Yu e.a, 2012; Zhang e.a., 2007) rather than on their organisational setting. Clearly, different stakeholders often have opposing interests regarding the performance of Vendor-managed Inventory systems and have the ability to use different sources of power during the implementation and usage of the system. The performance of these systems therefore, is not only dictated by technical aspects but also relates to organisational issues like partnership, trust and the sharing of information across organisational borders. Interestingly, only few studies have taken an integrated view on Vendor-managed Inventory systems and it is for this reason why an empirical study was conducted on the organisational barriers and enablers to Vendor-managed Inventory

Our full paper draws heavily on one in depth case study and four mini cases. In doing so, a framework for assessing the influence of different stakeholders on the usage of Vendor-managed Inventory systems is presented. Starting from the notion that Vendor-managed Inventory systems encompass a physical, planning, informational and organisational dimension, our framework heavily relies on the stakeholder salience theory and theories on partnership and trust to explore the organisational barriers and enablers to Vendor-managed Inventory. In the second part of the paper, this framework is used to reveal how different stakeholders influence the performance of Vendor-managed Inventory systems in the settings that were studied. The last sections of the paper elaborate on some of the main findings of the case studies.

In so doing our papers aims at contributing to the theory on inventory management by presenting a diagnostic framework on the role trust and partnership may have on the performance of Vendor-managed Inventory systems. Secondly, our full paper presents empirical case data aimed at exploring the complex interactions between the stakeholders when using Vendor-managed Inventory systems. Clearly, these interactions take place across

organisational borders and unravelling the associated dynamics can help in gaining an in depth understanding of the performance of Vendor-managed Inventory systems. Hopefully, this more in depth understanding will enable practitioners to overcome existing barriers to successful applying Vendor-managed Inventory strategies.

Keywords: vendor-managed inventory, case study, stakeholders, partnership

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OPTIMAL SCHEDULING FOR AN IMPERFECT MANUFACTURING SYSTEM OF DAMAGEABLE ITEMS WITH PRICE-SENSITIVE DEMAND

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Abstract: In this paper, a finite time-horizon deterministic EPQ (Economic Production Quantity) model is developed in imperfect manufacturing environment. The model is concentrated on damageable products where the rate of demand decreases exponentially with selling price. The objective is to find the optimal production quantity, production rate and product reliability that maximize manufacturer's total profit. The results are examined through numerical examples. Optimal Solution's sensitivity analysis is also performed with respect to the key parameters of the system.

Keywords: product reliability, imperfect production, damageable item, price varying demand

SUPPLY CHAIN INVENTORIES AND RESILIENCY: A META ANALYSIS

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The global, complex and uncertain nature of supply chains are increasing the call for improved supply chain risk management (SCRM) processes and practices that lead to better supply chain resiliency, resulting in improved operational and tactical performances. In this research we explore the integration of research from two critical domains namely, SCRM and supply chain inventory management (SCIM). Specifically, through a Meta analysis we seek to address the following research questions:

(1) What role does SCRM play in minimizing inventory risks;

(2) What are the operational, tactical and organizational antecedents of SCRM and how do these factors moderate SCIM in improving supply chain resiliency?

SCIM research points to factors that affect inventory policies at various stages and the related vulnerabilities. For example, the level of raw materials inventories is based on transaction cost economics theory and the role of power in a supply chain and the vulnerabilities include storage and transportation costs across the supply chain, payment terms and power position of a firm in the supply chain. Furthermore, results from analysis of inventories at all three levels point to mixed results in inventory reduction for firms engaged in improvement practices, such as just-in-time. However, growing demand for product variety, higher customer service levels, and greater demand uncertainty may be forcing higher inventory holdings in retail firms. Lastly, it is also clear that in addition to operational factors such as demand and lead time uncertainties, competition, business dynamics and business cycles impact inventory levels differently and the different policies seem to impact the inventory risks (increased carrying costs versus stock outs).

Using a systematic review procedure of the literature in the two domains we would combine the results of the different studies that connect SCRM and SCIM. Our analysis would provide a clear understanding of the factors (example: inventory policies, structure of supply chain, etc.), interrelation between them (in terms of information coordination) and the ensuing risk management (example: improving resiliency through adaptability or alignment).

Keywords: supply chain inventory management, supply chain risk management, meta-analysis, resiliency, adaptability & alignment

SERVICE LOGISTICS: ROLE OF SELF-DISTRIBUTION IN US HOSPITALS – A CASE-STUDY APPROACH

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Growing healthcare costs in developed economies have increased the focus on improving efficiencies across the healthcare supply chain to provide critical cost savings. Vertical integration of goods, such as medical-surgical products (Med-Surg.) is low in healthcare value chains because the costs of transacting with the marketplace for distribution and delivery are much less than the costs of attempting to take distribution in-house and coordinating all of these exchanges using hierarchical means. Typically, moving Med-Surg. for hospital systems involve a standard five-step distribution model of: receive in bulk from a manufacturer to a distributor warehouse; break it down into smaller volume; send it to a hospital; break it down again for use in different departments; and deliver it to the customer (example: surgical suites). However, our research team looked at a recent, nascent practice of **self-distribution**, where the hospital systems were moving to a three-step direct distribution model of: purchasing products direct from the manufacturer; receiving products in bulk and breaking them into a low unit of measure; and, delivering them directly to the hospital systems.

We did detailed data-collection through interviews with eleven hospital systems in the US that identified themselves as either completely into self distribution of their Med-Surg. Products, or in a continuum between distributor-managed-distribution or the traditional, outsourced distribution. Due to the newness of this phenomenon, we used the case-study approach. We collected data on the size and supply chain maturity with these health care systems, their journey towards self-distribution and the operational and financial impact.

Using the theoretical lenses of "supplier structural embeddedness," and "agency theory," we are able to understand the following: (a) Cost factors such as inventory, transportation and facilities and handling, and service factors such as time, variety and availability were the key drivers to switch to self-distribution; (b) Lack of distributor embeddedness, lack of trust with valuation of distributor's role and costs, hospitals learning from other hospital systems and even forming independent networks were key structural issues for the changeover; (c) Size of hospital systems and internal supply chain talent were key determinants of successful transformation; and (d) transformed hospital systems from viewing logistics not as internally neutral to but externally strategic leading to better cost control.

Keywords: hospital systems, self-distribution, agency-theory, structural-embeddedness, service logistics

INTERMEDIATE INVENTORY MANAGEMENT AT AN ALUMINUM TUBE MANUFACTURING PLANT

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Metal tube manufacturing plants start their manufacturing process with huge ingots of raw metal. These are then processed and extruded to tubes of different sizes and stored in intermediate inventory (referred to as blooms). Finally customer demand is satisfied by cutting the blooms to tubes of appropriate lengths. This research focuses on determining the best lengths of blooms to stock and the amounts to stock in inventory in order to minimize scrap and inventory carrying costs. This paper develops a two stage solution procedure for the bloom sizing problem. We provide a real world example and test our solution procedure with actual data from the application.

In the first stage, for a given p, we determine the set of p standard bloom lengths to stock in order to minimize total scrap costs. Ignoring the inventory costs while determining the standard lengths is justified in situations where the scrap cost dominates the inventory cost. We formulate the problem as a p-median location problem use a Lagrangean based algorithm to solve it. In this procedure, we dualize the p-median constraint and solve the subproblems (which are uncapacitated facility location problems) using a dual ascent procedure. We solve a few problem instances derived from real world data provided by a leading aluminum tube manufacturer. The p-median solution reduces scrap by an average of 70% when compared to the scrap incurred by current practice.

Once we choose the standard lengths, the next step is to determine the optimal stocking sizes for each of the standard lengths. We consider a multi-product inventory problem with ordering and inventory costs, penalty cost for not satisfying demand, a salvage value for excess stock, and revenue for satisfied demand. We also allow one level downward substitution at a substitution cost. If the standard blooms are indexed in the order of decreasing length, then a unit of bloom i can substitute for one unit of bloom i+1. We can repeat this two stage procedure for several values of p and pick the value which gives the maximum total revenue over the two stages. When tested with the real world data, the one level substitution inventory model increases net profit by an average of 1.5% when compared to the standard newsboy solution. The total inventory (measured in pounds of aluminum) carried decreases by an average of 1790 pounds for the one level substitution case.

Keywords: intermediate inventory, bloom-sizing, downward substitution, p-median solution, Lagrangean algorithm

AN INVESTIGATION OF THE RELATIONSHIP BETWEEN SUPPLY CHAIN INTEGRATION, FLEXIBILITY AND BUSINESS PERFORMANCE IN MANUFACTURING FIRMS

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Much has been written about flexibility as an important competitive criterion for manufacturing firms. Indeed, in the operations management literature flexibility is now considered as one of the key operations objectives in addition to quality, speed, cost and dependability. Furthermore, various classifications of flexibility have been identified in the literature including mix, volume, new product and delivery flexibility (Slack, 1991; Koste and Malhotra, 1999). However, many of the studies on flexibility have focused on internal mechanisms for delivering flexibility. Given that firms' supply chains now compete rather than the individual firms, the importance of network of firms within a firm's supply chain to the achievement of firm flexibility cannot be over-emphasized. In this study, we investigate the influence of supply chain integration on two aspects of flexibility – new product flexibility and volume flexibility. Beyond the internal drivers of flexibility, we posit that a well integrated supplier network encourages joint new product development efforts, visibility and sharing of information which provide a focal firm the ability to bring innovative products to market quickly and cheaply (new product flexibility) and the ability to change the level of aggregated output (volume flexibility) (Slack, 1991; Oke, 2005). Furthermore, we investigate the effects of new product and volume flexibility on a firm's business performance.

Based on a structural equation modeling of data collected from manufacturing firms, our analyses reveal that supply chain integration is positively related to both new product and volume flexibility. Similarly, new product flexibility and volume flexibility are both positively related to business performance. Interestingly, we found that both new product flexibility and volume flexibility are partial mediators of the link between supply chain integration and performance suggesting that there are other potential processes through which supply chain integration affects performance. The theoretical and practical implications of the study are discussed.

Keywords: supply chain integration, flexibility, manufacturing

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PURCHASING AND COMPETITIVENESS OF A COMPANY - THEORY AND PRACTICE IN INDUSTRIAL ENTERPRISES IN THE CZECH REPUBLIC

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Corporate procurement represents one of the factors in increasing corporate competitive abilities. This shows namely in flexibility of procurement upon changes in company product and product range policy according to market/customer demands. The objective of our research is long-term monitoring of procurement position within the frame of corporate value-creation chain. Analyses are namely focused on links between procurement and other elements in the chain, their readiness and mutual assistance upon flexible accommodation of the company to customer requirements. Gradual interviews at more than 300 manufacturing plants in the Czech Republic resulted in a set of information regarding company compliance with customer comments and insights, respecting the renowned slogan „our customer our king", attitude to innovations and internal approach to implementing market orientation in the following areas: marketing, sales, research and development, production technical preparation, procurement and logistics. Analyses also focus on flexibility on the part of contractors. From a complex viewpoint, using targeted questions, the research deals with perception of required flexibility by the company and obstacles standing in its way, i.e. barriers to applying marketing principles. Analysis of a wide range of specific data enables defining measures leading to increasing corporate competitive abilities, i.e.:

- thorough implementation of marketing concept, including application of procurement marketing principles and partnership relations,
- application of product management principles with the objective of creating value for the customers and company,
- implementation of full standardisation (in case of buying e.g. with input elements and material relations in consumption etc.),
- trade from hierarchic structures to process management,
- integration of planning and management within the corporate value-creation chain (sales – production – procurement) also within the frame of the entire supply chain.

FORECASTING OF INTERMITTENT OR LUMPY DEMAND: STATISTICAL ACCURACY AND INVENTORY CONTROL PERFORMANCE

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The evaluation of alternative methods for demand forecasting has traditionally been based upon statistical error measures. Various studies have observed that performance with respect to these standard accuracy measures may not translate into inventory systems efficiency. For instance, Gutierrez et al. (2008) and Mukhopadhyay et al. (2011) have found that neural networks and an optimally-weighted moving average, when applied to an industrial dataset exhibiting lumpy demand, perform better overall across different scale-free error measures than single exponential smoothing, Croston's method (Croston, 1972), and the Syntetos-Boylan approximation (Syntetos and Boylan, 2005). The latter three methods have been well-referenced in the intermittent demand forecasting literature. Solis et al. (2010) conducted a preliminary investigation involving single-run simulations on the dataset (as in Eaves and Kingsman, 2004), applying the forecasts in an order-up-to (*T*,*S*) periodic review system. They observed much lower mean fill rates (i.e., inferior customer service levels) when the "best" method (based upon the statistical accuracy measures) is used.

In the current study, we apply various forecasting methods to an industrial dataset involving about 1500 items generally held in stock at a distribution center and a number of manufacturing plants of a firm operating in the professional electronics sector. We first categorize the demand for each stock keeping unit (SKU) as smooth, erratic, intermittent, or lumpy, according to a theoretically coherent scheme proposed by Syntetos et al. (2005). Given that the various SKUs are used for projects, sales, and service, many of them exhibit intermittent or lumpy demand. We divide the demand data series, covering 66 four-week "months", into initialization, calibration, and performance measurement blocks (as in Boylan et al., 2008) for empirically investigation of forecasting performance. Finally, we empirically evaluate inventory control performance, particularly for SKUs with intermittent or lumpy demand, using simulation. We use the negative binomial distribution (e.g., Syntetos and Boylan, 2006; Boylan et al., 2008; Syntetos et al., 2009) to model intermittent demand and a two-stage distribution involving the uniform and negative binomial distributions to model the lumpy demand for some SKUs. We will report on our findings from our empirical investigations of both forecast accuracy and inventory control performance.

Keywords: intermittent/lumpy demand forecasting; forecast accuracy; inventory control; order-up-to periodic review system; simulation

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INVENTORY CONTROL PERFORMANCE OF A NEGATIVE BINOMIAL APPROXIMATION IN A MULTI-ECHELON INVENTORY SYSTEM

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Graves (1996) developed a multi-echelon inventory model involving a 'virtual allocation' system. In the one-warehouse, N-retailer case, a negative binomial distribution is used to approximate the distribution of a random variable called 'uncovered demand'. Graves developed procedures to search for (approximately) optimal base stock levels at the warehouse and the retail sites under either a probability of no stockout criterion or a fill rate criterion.

Two earlier multi-echelon inventory studies (Graves, 1985; Lee and Moinzadeh, 1987) have similarly used negative binomial approximations. In all three models, computational evidence has been offered in support of the approximation. Solis et al. (2007) provided, for the latest model (Graves, 1996), the first known analytical evaluation of the effectiveness of such an approximation. They observed that, in certain instances, exact and approximate distributions may exhibit relatively significant differences at specific realizations of uncovered demand. Nevertheless, relative deviations between cumulative probabilities of the exact and approximate distributions of uncovered demand continue to be very small, particularly at the higher cumulative probabilities (0.80 or more) associated with service levels. Cumulative probabilities of uncovered demand are applied in the search procedure for base stock policies under a probability of no stockout service criterion. However, when a fill rate criterion is applied, Graves' search procedure is based upon evaluating expected backorders at a point in time just before a replenishment arrives, with individual probabilities of uncovered demand being used in computing expected backorders. The effectiveness of the approximation under the fill rate criterion remains doubtful, especially in cases where relatively significant deviations exist between exact and approximate probabilities.

In the current study, we develop simulation models within the AnyLogic platform for each of 16 test scenarios in order to evaluate the performance of base stock levels determined, using Graves' search procedures, to be "optimal". Based upon the earlier analytical evaluation (Solis et al., 2007), base stock policies selected for the probability of no stockout criterion perform very well, as expected. We will also report on how the "optimal" base stock policies determined by the search procedure for the fill rate criterion actually perform in the simulation experiments.

Keywords: multi-echelon inventory model; one-warehouse, N-retailer system; negative binomial approximation; optimal base stock levels; modelling and simulation

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THE STOCHASTIC ECONOMIC LOT SIZING AND SCHEDULING PROBLEM: AN ITERATIVE ALGORITHM FOR DYNAMIC SEQUENCE AND FIXED PITCH PRODUCTION STRATEGIES

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This paper presents an iterative algorithm used to solve a class of the stochastic economic lot sizing and scheduling problem (SELSP).

The relevance of the SELSP is evidenced by both the vast literature on these kind of problems and its vast occurrence in manufacturing and process industry. SELSP is concerned with replenishing inventory of multiple products subject to random demand in an optimal or close to optimal way. The replenishment is performed by a single machine, on a single stage, and a setup time is incurred whenever the server switches products. We restrict our analysis to problems with setup times independent of the production sequence. The presented algorithm is intended to a production strategy composed by dynamic sequencing and fixed pitch.

Facing the random demand issue, dynamic sequencing strategies are very promising due to their capacity to add flexibility to the solution - even though they have received little attention in the literature. The sequence rule used here states that the next product type to be produced shall be the one closest to depletion. If all stocks are above their order points, the machine is kept idle.

The pitch concept means that all production lots have the same execution time (including setup), independently of the product being manufactured. Using pitch aids in: (i) controlling the production in an easier way (ii) friendly implementing the proposed solution (iii) enabling one to invest in time and cost setup reduction. In addition, pitch has a wide usage in the industry, being also part of the lean manufacturing framework.

Using the two strategies described above, the proposed algorithm solves the SELSP calculating the pitch, product lot sizes and order points. To achieve the solution the algorithm iteratively combines two procedures:

- An iterative process for non-linear optimization problems, which selects and refines pitches.
- A discrete stochastic simulation routine used to find the minimal order points for individual products, for a single pitch, with a constraint on the pre-defined service level.

The fast convergence of the algorithm to minimal inventories makes it suitable for frequent use in industrial sized instances. It is worth pointing out that the algorithm satisfies the requested service levels.

Keywords: SELSP, inventory management, scheduling, lot sizing, simulation

DOES INVENTORY THEORY MATTERS EVEN WHEN WE CAN'T USE IT? AN EXPERIMENT BASED ON THE BEER GAME SIMULATION

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Objectives: Inventory theory is a very complex field . However, the gap between an increasingly complex theory and rather basic applications is astonishing. Our reading is that this gap is due to two major problems:

a) Most papers have rather tight requirements and assumptions which are very seldom met in real life problems (i.e., models are irrelevant for practical purposes);

b) Very often models are quite complex and their application in a real context creates significant costs; part of these costs are the cost of managing humans that have to buy into this.

Why do we still teach it? Does it really matter?

We use a classic beer game experiment to test whether teaching a theory that is hardly applicable in practice still makes sense. Our hypothesis is that teaching inventory models makes students realize how inventory systems work and help them to get a decent understanding of inventory dynamics and how to control and manage them. While the inventory models might not be applicable per se, the insights are applicable and indeed add a great deal of value.

Data: 258 student from the industrial engineering course at Politecnico di Torino have played the beer game. We split them into two groups. The first group was taught the (Q;R) inventory model before the beer game simulation and the second one was taught the (Q;R) model after the beer game simulation. Other than that the students in the two groups are very similar and both were exposed to forecasting, deterministic inventory planning and the newsvendor model prior to the experiment.

Clearly the (Q;R) model cannot be used in the beer game since in the beer game demand distribution is not known in advance, there is no fixed ordering cost , inventory control is periodic rather than continuous. So the (Q,R) is not applicable to the beer game and thus it should not make any difference.

Hypothesis 1.: We put forward the hypothesis that students that were exposed to the (Q,R) model (treatment sample) outperform the students that were not exposed to the (Q;R) model; this would lead to the non obviouos finding that inventory theory improves performance even when theory is hardly applicable to the planning problem at stake.

In our experiments we also collected additional information such as the quality of single students in each position of each supply chain, their age and gender, and asked them to estimate retail demand, at the end of the beer game simulation.

With these additional pieces of information we can estimate the quality of planning for each individual chain and each single player. We put the following hypotheses forward:

Hypothesis 2.: In many companies supply chain planners have hardly any formal education in supply chain or inventory planning so the quality of human capital is often low. On the contrary, we argue that quality of human capital matters: The higher the quality of students in a supply chain the lower the total cost for the chain. Interestingly we can measure the quality of the students both as the average quality of the four stages of the beer game supply chain or as the quality in each single role of the supply chain (retailer, distributor, wholesaler, manufacturer). We argue that average quality might not be a very good predictor of total chain cost as wrong planning at the retail stage might disrupt the whole chain. On the contrary, we try to measure the quality of each single player planning as the mismatch between planned supply and demand for each single stage of the supply chain and test whether it is correlated with the quality of students. This analysis, in our opinion, has crucial implications for companies hiring inventory and demand planners.

The full paper analyses the above issues quantitatively and discusses them in the light of both literature on the beer game and literature about education on inventory theory.

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