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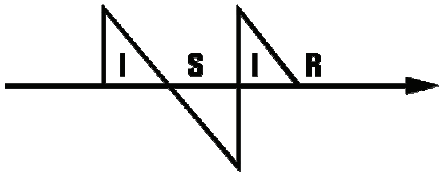

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PLENARY PAPERS

FORECASTING AND INVENTORY MANAGEMENT OF SERVICE PARTS

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Service parts are very common in many industries and forecasting their requirements is an important operational issue. In the last ten years, there have been many advances in forecasting methods, demand information sharing strategies, and the design of Forecast Support Systems. Some work has also been done on the value of judgemental adjustment of statistical forecasts. In this paper, these developments are reviewed and avenues for further research are explored.

Improvements of forecasting procedures for spare parts may be classified under three headings: i) Pre-processing, ii) Processing, and iii) Post-processing.

i) 'Pre-processing' includes the rules or protocols that designate a spare part as fast-moving or slow-moving, intermittent or lumpy. Operational classification rules for service parts are reviewed, including some empirical evidence on sensitivity to cut-off values.

ii) 'Processing' denotes the application of the appropriate forecasting method, when the classification phase has been concluded. For faster moving service parts, variations of exponential smoothing are still popular choices for software packages. For slower-moving spares, a number of innovations in forecasting methods have been developed recently. These are important developments and are discussed in some depth.

iii) 'Post-processing' includes any adjustments made by the user to the statistical forecast. Judgemental methods, such as the direct use of managers' opinions, are often applied in practice. Empirical findings on forecast accuracy have shown mixed results. However, some positive evidence for slow-moving items will be reviewed in this paper.

The improvement of forecasting procedures is not the only approach to enhancement of forecasting performance. There has been much discussion on the amplification of demand noise as demand progresses up the supply chain (the 'bullwhip effect'). It has been suggested that the sharing of demand information will enable higher echelons to forecast demand more accurately. This stream of research will be investigated further in the final section of the paper.

OPTIMAL INVENTORY AND PRICING POLICIES FOR REMANUFACTURABLE LEASED PRODUCTS

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In this presentation we consider a company which leases new products and also sells remanufactured versions of the new product that become available at the end of their lease periods. When the amount of end-of-lease items in stock is not sufficient to meet the demand for remanufactured products, the firm may purchase additional cores from a third-party supplier.

We develop a dynamic programming formulation for determining the optimal price of remanufactured products, and optimal payment structure for the leased products. We also determine the optimum amount of inventories to hold for different customer segments. Our objective is to maximize the discounted system-wide profit over a finite horizon. The profit function consists of revenues that are obtained from remanufactured product sales and through leasing, remanufacturing and manufacturing costs, inventory holding and shortage costs.

We consider two different demand models that map a potential customer into one of the product segments (a remanufactured product customer or a customer for a leased product with a particular lease period) for a given price/lease payment vector. In the first model, each potential customer is tagged as a remanufactured product customer or a leasing customer (with a specific duration) according to a probability distribution and the demand level for each segment is determined through a linear price-demand function. In the second model, we consider a consumer choice model where a customer is assigned to a segment based on her willingness-to-pay for a remanufactured or brand new product.

We explore several structural properties of the discounted profit function for both of the demand models and provide insight on the behavior of pricing and inventory policies. We also investigate the effect of key product characteristics such as deterioration in age, cost of shortage in remanufacturable product inventory, and key market characteristics such as relative willingness-to-pay for buying a remanufactured product and relative willingness-to-pay for leasing a new product on optimal pricing policies through a computational study. Since the discounted profit function is highly non-linear, we use a modification of Nelder-Mead Simplex Search Method for finding the numerical solutions. Our computational study provides managerial insight on determining the prices of leased and remanufactured products in order to balance demands of different customer segments, avoid excess inventories and shortage costs.

INVENTORIES, FLUCTUATIONS AND BUSINESS CYCLES

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The broad purpose of this paper is to explore the role that inventories play in the business cycle. This is an old question but we use new techniques to investigate the question and thereby shed new light on the relevant issues.

Within the broad purpose of the paper, there are two objectives. One is to identify the basic facts regarding the role that inventories play in the business cycle. We use new methodological procedures for characterizing the features of business cycles advanced by Harding and Pagan (2002). Basic facts about the role of inventories in the business cycle are invariably presented via means, variances, and co-variances of important variables. In contrast, in this paper, we use new techniques that emphasize the effect that inventories have on turning points and the length of expansions and contractions of the business cycle. These give rise to new insights into the role that inventories play in the business cycle.

A second objective of the paper is to investigate whether better inventory management techniques are responsible for the decline in the volatility of GDP growth in the US and many other countries since the mid-eighties. Several hypotheses have been advanced to explain this phenomenon. These include better monetary policy, "good luck" in the sense of favorable shocks to the economy, or better inventory management techniques. The second objective of the paper is then to shed light on whether better management of inventory positions by business firms can explain this phenomenon. The basic idea is that technological advances in inventory control methods have permitted business firms to smooth the production of output in the form of value added or GDP.

To investigate this question, we extend the model developed by Humphreys et al (2001) to analyze movements in the growth rate of GDP in the goods sector of the U.S. economy. The model is particularly advantageous for analyzing the question at issue because it explicitly distinguishes between finished goods inventories and materials and supplies inventories. This is very important because our analysis of the basic facts indicates that it is likely to be materials and supplies and work in progress inventories rather than finished goods inventories that are critical to the explanation for the decline in the volatility of GDP growth. The model also encompasses potentially important exogenous forces at work, including sales, real raw material prices and real wage rates, and technology shocks. We estimate the parameters of the model using quarterly data from the US economy. The estimation procedure uses recent developments in econometric methods to deal with stationarity problems in the data. The empirical work thus yields reliable estimates of important parameters that are needed to address the basic question. Once the model is estimated, we use simulation analyses to see what particular features of the model can explain the decline in the volatility of the growth rate of GDP.

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ANALYSING RISK FLOWS IN SUPPLY CHAINS

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Productions in the early years were simple; single flow of production, where product is sent directly to the market by the manufacturer. Nowadays, shorter product lifecycle and increasing demand among all have led to supply chain expansion. Due to this expansion, supply chain network has becomes more complicated and difficult to manage. Any hiccup transpired within the supply chain will cause delay and even disruption (Buzacott, 1971). Identifying the cause of disruption and potential alternatives to prevent it has become important in managing a supply chain.

There are various studies on Supply Chain Risk Management and Risk Management. However, we found the early literature were mainly descriptive (Arlbjörn and Halldorsson, 2002; Carter and Ellram, 2003; Chen and Paulraj, 2004; Harland et al., 2003; Hood and Rothstein, 2000; Khan and Burnes, 2007; Swaminathan and Tomlin, 2007; Tan, 2001; Tang, 2006; Taylor, 2005; Tummala and Mak, 2001; Yu, 2002; Zsidisin, 2003). In addition, Tang (2006) believes despite the growth of research in this area, there are many issues remained to be explored and studied. According to our opinion, supply chain disruption is caused by interruption of various flows in the system. Therefore, in this paper we aim at identifying and classifying potential risk associated with different flows in supply chains.

This study is conducted by reviewing literatures on relevant journals published for the last ten years. The review has piloted us to identify the major flows in supply chain network; material flow, cash flow and information flow. Even though it is not necessary, more often a common cause of disruption could be affecting all three flows since they are often related and interconnected. For example, a natural disaster of earthquake would disrupt the whole supply of material, shutdown information network and at the same time may cause stock market to nosedive. In this study, the early literatures are classified into categories associated with the above three flows. Causes of risk, as well as existing and potential analysing and solution methods are also presented.

This research is the cornerstone in providing further research notions and ideas. In particular, based on this research framework we should outline potential quantitative methodology for managing risk.

Keywords: *Supply Chain, Supply Chain Disruption, Risk Management*

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1.
ECONOMICS OF INVENTORIES

AN EMPIRICAL ANALYSIS OF CAPITAL ACCUMULATION

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Duncan K. Foley's mathematical formulation of the Circuits of Capital (1982a, 1986a) presents a coherent framework to operationalize and utilize the Circuits of Capital in macroeconomic analysis. The Circuits of Capital, rooted in the ideas of Physiocrats, Classical Political Economists, culminates in Marx's approach to macroeconomics. Circulation of capital is traced through stocks of total inventories, inventories of finished goods, and money.

Turnover time of capital through these stocks is extracted from aggregated balance sheet and income statement data to measure the corresponding production, sales, and investment delays. Knowledge of these delays allows the linking of value from various phases of the circuit, and to measure the time dependent parameters of the circuit of capital — monetary expression of labor time, rate of surplus value, and the capitalization rate. This paper will utilize a *stock/flow* measure of delay as a first estimate, and introduces a dynamic method of measuring delays that more adequately deals with time dependent processes of capital accumulation.

INVENTORY INVESTMENT AND SECTORIAL CHARACTERISTICS IN OECD COUNTRIES

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This paper is a new wave in a research stream conducted in order to disclose effects of macroeconomic factors of national inventory investments in the developed countries. In papers presented at earlier ISIR Symposia we dealt mostly with the characteristics of GDP's output (distribution) components, studying their effect on macroeconomic inventory behaviour in OECD countries. Among many other statements we have suggested that there should be a decreasing trend in macro inventory levels if we consider the many inventory reducing efforts made in these countries at the managerial level (the introduction of MRP, JIT, SCM and other "magics" in companies' operation). However, this decreasing tendency – if exists at all, which can be stated only with some reservations - is mostly counterbalanced by factors stemming from the increased complexity of economic activities.

We started discovering the effects of complexity by examining the input components of GDP. In this paper we analyse the connection between sectorial structure, its changes and inventory investment in eleven OECD countries, applying multivariable statistical methods. At the time of writing this abstract we are still in the analysis process, but the results obtained so far are very promising.

REDUCTIONS IN THE BULLWHIP EFFECT AND REDUCTIONS IN GDP VOLATILITY

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Using quarterly data for the U.S. manufacturing and trade sector divided into 2-digit and 3-digit SIC industries from 1967 through 2001, we examine the change in amplification ratios for the period since 1984 relative to amplification ratios for the 1967-1983 period. Considerable evidence is found that trade sector firms (retail industries and merchant wholesaler industries) reduced the variance of their orders relative to the variance of their sales, which is consistent with a reduction in the bullwhip effect along distribution chains. On the other hand, the evidence for manufacturing industries is mixed. This is consistent with our findings that about two-thirds of the reduction in covariance associated with the "Great Moderation" of GDP is associated with distribution chains.

BUSINESS CYCLE VOLATILITY AND INVENTORY BEHAVIOUR: AN ANALYSIS FOR EUROPE USING BUSINESS SURVEY DATA

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In recent years a number of studies have investigated the reduction in volatility registered for important macroeconomic variables in the US, such as GDP growth (Stock and Watson, 2002; McConnell and Perez-Quiros, 2000; Blanchard and Simon, 2001; Arias, Hansen, and Ohanian, 2006). Various explanations have been advanced for these findings: alternatively, imputing the reduction in volatility to better monetary policy management, technological innovation, or "good luck". The aim of this paper is threefold: first of all, we focus on the Euro area in order to reach a better understanding of the stylised facts of European business cycles as compared with those of the US. In particular, we look for possible breaks in the Euro Area Data Generating Process using both univariate (Bay, Perron, 1998; Stock and Watson, 2002) and multivariate testing techniques (Bai, Lumsdaine, and Stock, 1998). Secondly, we propose to undertake an investigation of the technological innovation hypothesis as an explanation for the great moderation, focusing on advances in inventory management techniques due to computerization. However, in contrast to the US, inventory data in Europe are not directly derived from specific quantitative surveys on the industrial sector but are obtained either as a residual from National Accounts or from qualitative surveys on the industrial and retail sector. If our findings confirm that the reduction of volatility in economic activity is matched by that of inventories, we will inspect more closely the variance of the latter, looking at compositional, sectoral and possibly national level effects. In fact, a reduction in overall inventory volatility may be due either to a reduction of volatility at the industry/national level or to changes in the co-movement among industries or a combination of the two (Irvine and Schuh, 2005; Herrera and Pesavento, 2007). The issue of the contribution of specific sectors to the reduction of both inventories and business cycle volatility will be also addressed, using the methodology proposed by Irvine and Schuh (2005).

Finally, after providing comprehensive evidence of the stylized facts regarding reduction of business cycle volatility and the contribution to that of inventory behaviour, we model the channels of transmission of inventories changes to general activity. In this respect, we use the structural model of the firm proposed in Maccini and Pagan (2007) to explore the effects of inventory movements on output.

Keywords: *European survey data, inventory behaviour, Business cycle stylized facts, structural breaks*

JEL Classification: C32, E32

ON THE CONVEXITY OF NEWSVENDOR GAMES

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This study considers a multiple newsvendor situation that consists of n retailers, all selling the same item with common purchasing costs and common selling prices. In the inventory literature, it has been shown that groups of retailers might increase their expected joint profit by inventory centralization, which means that they make a joint order to satisfy total future demand (see, e.g., Eppen (1979), and Chen and Lin (1989)). Afterwards, several papers have analyzed the problem of allocation of the gains from inventory centralization using the tools provided by cooperative game theory, mainly focusing on the core. Intuitively, the core of a newsvendor game can be interpreted as the set of payoff vectors for which no retailers have an incentive to leave the grand coalition, which consists of all retailers, and form a smaller coalition. The resulting newsvendor games are shown to have non-empty cores in the literature (see Hartman et al. (2000), Müller et al. (2002) and Slikker et al. (2001)).

This study investigates convexity of newsvendor games. Convex games are well-known for having several nice properties related to their cores. First of all, the marginal vectors of a convex game are the extreme points of the core. Besides, the bargaining set coincides with the core, and the Shapley value is the barycenter of the core. For newsvendor games, convexity states that the marginal gains from inventory centralization and order coordination will be higher if a retailer joins a bigger coalition. We focus our analysis on the class of newsvendor games with independent symmetric unimodal demand distributions after providing several examples outside this class that are not convex. Several interesting subclasses, containing convex games only, are identifed. Additionally, we illustrate that these results cannot be extended to all games in this class.

Keywords: *game theory, inventory centralization, newsvendor, convexity*

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2.
INVENTORY MANAGEMENT

TACTICAL CAPACITY MANAGEMENT UNDER CAPACITY FLEXIBILITY IN MAKE-TO-STOCK SYSTEMS

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In many production systems a certain level of flexibility in the production capacity is either inherent or can be acquired. In that case, system costs may be decreased by managing the capacity and inventory in a joint fashion. In this paper we consider such a make-to-stock production environment with flexible capacity subject to periodic review under non-stationary stochastic demand, where we allow for positive fixed costs both for initiating production and for acquiring external capacity. Capacity can be defined as the total productive capability of all productive resources utilized, such as workforce and machinery. These productive resources can be permanent or contingent. We define permanent capacity as the maximum amount of production possible in regular work time by utilizing internal resources of the company such as existing workforce level on the steady payroll or the machinery owned or leased by the company. Total capacity can be increased temporarily by acquiring contingent resources, which can be internal or external, such as hiring temporary workers from external labor supply agencies, subcontracting, overtime production, renting work stations, and so on. We refer to this additional capacity acquired temporarily as the contingent capacity. Capacity flexibility refers to the ability of adjusting the total production capacity in any period with the option of utilizing such resources. Our focus is on the tactical level capacity management which refers to the determination of in-house production capacity while the operational level integrated capacity and inventory management is executed in an optimal manner. We first develop a dynamic programming model to represent this relatively complicated problem. We prove that determination of the capacity level is a convex minimization problem when the fixed costs are negligible for the multiple periods problem. When the fixed costs are positive, we characterize the optimal usage of permanent and contingent capacity levels as well as the optimal production quantities for the single period problem, and elaborate on the characteristics of the optimal solution for the multiple periods problem. Our analysis reveal that the optimal permanent capacity (i) decreases as the costs of the contingent resources decrease, (ii) increases as the fixed cost of production increases until a threshold level, after which it is economically better to conduct all of the production with contingent resources, and (iii) decreases as the unit cost of permanent capacity increases. We have shown (in some cases analytically and in some cases numerically) that there are many problem instances where the optimal permanent capacity level is zero. This points to a situation where all production is outsourced. We also show the existence of cases where such an action is optimal even if the contingent resources are more expensive. We also discuss several useful managerial insights as to the impact of demand variability on the optimal capacity levels, the effect of operating at suboptimal capacity levels, and the value of utilizing flexible capacity based on numerical analysis.

Keywords: *Inventory, flexible capacity, capacity management, stochastic demand, fixed costs*

INVENTORY MANAGEMENT POLICIES FOR MULTI CHANNEL DISTRIBUTION NETWORKS

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In this work we deal with the inventory management of final goods in a multi-echelon, multi-channel distribution system. In particular, we present the evolution of a distribution system of a manufacturing industry operating in the Italian market, while comparing the distribution costs of the corresponding investigated scenario.

We first analyse a distribution network made up of three levels: central depots, regional depots and customers. Customers are split into two classes: retail clients and big ones. Goods are distributed throughout two different supply channels: 1) a traditional channel, in which clients are served by regional depots, that in turns are supplied by the central ones; 2) a direct channel, where clients are characterized by a large demand and are served directly by a central depot.

The assignment of both peripheral depots and big clients to central depots is known as well as the assignment of retail clients to the peripheral depots.

We assume known the customers' demand that is expressed in terms of units of a single representative commodity. Inventories can be stocked both at central and regional depots.

Given the above described network, the problem is to determine the optimal inventory level for central and peripheral depots within each time period $\tau \in T$ in a given horizon T, with the aim of minimising ordering, inventory, stock out, and transportation costs, whilst satisfying capacity and requirements constraints and granting a certain customers service level. The inventory policy is based on a periodic review policy (e.g. every day) in which goods are ordered when inventories are less than a given amount; the quantity to order is defined for restoring inventories and minimising the logistic costs. We propose a Mixed Integer Linear Programming model (MIP) for solving this problem and present the computational experience with respect to the above different operative conditions.

Then, we optimize the flow of goods in the existing network by first modifying the assignment of the big clients and second changing the assignment of both big clients and regional depots to the central ones. These aspects are included in the previously defined MIP model.

Successively, two different company' decisions related to the inventory stock points and their location are evaluated and compared. In one case the network is modified by changing the stock points, in such a way that regional depots are replaced by transit points and central depots remain the only stock points in the network; in last case, the location of the central depots, that are the only stock points of the network, is discussed.

Finally, we compare a lot of scenarios characterised by different initial stock situations, different customers' demands, different customer service level to grant for each network configuration.

A MULTIPLE PRODUCT JOINT SHELF REPLENISHMENT DECISION SUPPORT SYSTEM FOR THE RETAIL INDUSTRY

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Out-Of-Stock (OOS) i.e. the temporary unavailability of items on shelves is a major problem in retail industry, since retailers face a direct loss (about 4%) of their potential sales. According to the Gruen et al. (2002) and Vuyk (2003) studies, OOS is mostly attributed (72%) to bad store ordering and shelf restocking practises. Until now, most researchers have focused on the extent and the causes of the OOS, but this research is more interested in the way product availability could be improved through more efficient shelf replenishment processes.

OOS problem is considered to be an inventory management issue. According to the available literature, the control of inventory has caught the attention of many prominent researchers with replenishment of 1(N) retailers from 1(N) central warehouses to be considered mostly. Much attention has been devoted to classical inventory models, but no model of shelf replenishment (restocking) is found in the literature. Only the shelf space allocation literature is relevant for developing further understanding of the shelf replenishment process (Zufryden, 1986; Yang and Chen, 1999; Dreze et al., 1994; Urban, 1998; Urban, 2005).

Therefore, motivated by the perennial OOS problem in retail industry, this paper proposes a multiple-product, single-echelon shelf replenishment model for the retail sector, where shortages are possibly allowed and joint replenishment is imposed. The retailer faces deterministic demand and the lead time is zero. A cost optimization function is defined as the sum of shelf replenishment cost, shelf holding cost and lost sales cost. The model has two decision variables: the time between two successive shelf replenishments (shelf replenishment cycle) and the shelf space allocated per product. However, demand is a multivariate function; thus, this model has been extended to incorporate the effect of shelf space allocated per product on the demand of the product.

Exact analysis establishes that it is optimal for the retailer to operate without shortages when the demand is constant. Further, shortages allowed, implies that the least profitable product(s) should not be traded at all. Overall, the exact analysis approach provides the shelf replenishment cycle and the shelf space of each of N products and also a closed form solution to the product assortment problem. This analytical model is the core part of a decision support system that provides with a cost efficient joint shelf replenishment cycle for the multiple products of a department in a retail store. Six months history of Point-Of-Sales data and shelf space allocation data of ninety products from four categories have been utilized for validation purposes. The analytical model proposes new values for the shelf space and the shelf replenishment cycle of each product in the category. For each proposed value of the shelf replenishment cycle, the total cost of the shelf replenishment of the products is calculated to finally find a cost efficient joint shelf replenishment cycle for the products of the category.

Keywords: *Out-Of-Stock, shelf replenishment, analytical model, retail inventory*

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ENVIRONMENTALLY RESPONSIBLE INVENTORY MODELS: NON-CLASSICAL MODELS FOR A NON CLASSICAL ERA

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The International Society for Inventory Research (ISIR) considers inventory from three points of view: inventory in the national economy, inventory management, and mathematical models of inventory. Mathematical models of inventory typically include the three inventory associated costs of surplus, shortage and ordering. These classic inventory models are then analysed so as to choose inventory parameters that usually minimise the total cost of operating the inventory system being investigated.

Unfortunately classic inventory models do not provide a meaningful basis for analysing many real and increasingly important practical inventory problems and situations. It is therefore not surprising that over recent years, several authors have discussed these issues in broad terms and suggested that a new paradigm needs to be developed.

This paper develops some specific aspects of this discussion. In particular, the paper identifies a range of inventory problems that are not covered appropriately by traditional inventory analysis. One of these is to design responsible inventory systems, i.e. systems that reflect the needs of the environment. The paper then examines the importance of inventory planning to the environment in greater detail. For example, packaging is important, not only because of its costs and the protection that it provides to the inventory items, but also because of its eventual effects on the environment in terms of the use of resources and potential landfill. For similar reasons, waste, which can result from poor inventory management, is highly important. The location of stores is important because location affects transport costs. Thus the influence of the secondary aspects of most inventory models; packaging, waste and location are important but, even more important are the inter-relations with the total system. In particular, the location of the manufacturing plants and the effect that inventory planning has on the logistics chain, potentially have considerable environmental implications. Inventory is part of a wider system.

However, until the cost charged for an activity reflects the true environmental cost of that activity, it is likely that decisions will be made on the basis of erroneous data. In that situation, we are faced with either determining the environmental cost of specific actions or to use environmental costs that are somewhat contrived; in which case it may be more sensible to use very different performance measures and models. The paper discusses these ideas and ways in which inventory policies may reassure us with our environmental concerns.

Keywords: *inventory, environment, modelling*

MANAGERS' VIEW OF A NEW INVENTORY PARADIGM

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As a consequence of fundamental transformations in the nature and structure of global business processes the role of inventories has substantially changed in the past decades. This change went on mostly implicitly. Inventories were dropped from the focus, the attention of management turned towards new approaches (many of which directly of indirectly influence inventories: like the management of supply chains, process-orientation, performance measures, partnership management, etc) and enjoyed the benefits the improvements in inventory efficiency achieved by application of these approaches.

This situation can be considered favourable; however, I am convinced that further gains can be obtained with a renewal of inventory management. For that, a new paradigm of inventory management must be formulated. Academics can play a role in the formulation of this paradigm, based on the rich experiences in inventory research accumulated in the past decades – but most certainly, the new paradigm has to be closely connected to managers' perception of the new role of inventories.

In a paper at the 2004 ISIR Symposium I had put down a possible set of fundamental assumptions of a new paradigm. In another paper in 2006 a test survey was presented. In this paper results of a full-scale survey are analysed. 140 managers had completed a questionnaire purposefully prepared for this analysis, from all sectors of the Hungarian economy. Their view on inventories and the new paradigm was connected with their professional background and company characteristics (size, sector, supply chain position) and general view of business trends. We used advanced statistical methodology for evaluation of the results, which overwhelmingly support the fundamentals of the new paradigm.

THE IMPACT OF LEAN PRACTICES ON INVENTORY TURNOVER

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Each company has to invest a lot in manufacturing management programs, methods and technologies in order to remain competitive. One very popular solution nowadays is lean management, which consists of several manufacturing practices such as process focus, pull production, quality development, total productivity maintenance, continous improvement, worker empowerment or supplier development. The main objective of lean management is to satisfy customer needs on the highest possible level through the elimination of wastes. Sources of waste can be overproduction, faulty products, suboptimized processes, needless waiting, movement or transportation and excess inventory. Hence successful implementation of lean management should greatly affect the company's inventory management. In this paper we analyze the effect of using lean manufacturing practices on inventory turnover which reflects the use of effective inventory management practices (Vastag – Whybark, 2005).

We use the data of an international survey (IMSS – International Manufacturing Strategy Survey), which contains 711 companies in 23 different countries from the ISIC sectors 28-35. Manufacturing practices evolve from time to time along a life cycle, so lean implementation also has several different levels (Voss, 2007). In order to reflect this phenomenon we use cluster analysis to separate manufacturers by the extent of their leanness. Next we compare the clusters to show whether there is any significant differences in their inventory practices. According to our hypothesis the level of company leanness has a positive relationship with the company's inventory turnover rate, hence a firm with wide application of lean manufacturing practices will have a higher inventory turnover than those who do not rely on lean management.

Apart from the article of Vastag and Whybark (2005) – who used the Global Manufacturing Research Group (GMRG) database – the investigation of inventory management was not in the focus of recent manufacturing survey researches. We think that our research can provide valuable empirical test results for both lean and inventory management purposes. For further research the model presented in this paper can be extended to involve business performance in itself too.

Keywords: *lean, manufacturing practices, inventory management*

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VALUE OF INFORMATION SHARING AND PROFIT ALLOTMENT BASED ON SUPPLY CHAIN COOPERATION

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To maximize customer value created by a supply chain system as whole one of the key issues in supply chain management is how to have profit and benefit properly shared between partners in an effective manner of the supply chain integration. In this regard, information sharing between partners plays a rather important role in business process reengineering and management integration of the supply chain, and to what extent the information sharing can be realized depends on the value it may create for the supply chain system and is closely connected with the manner of profit sharing between partners.

The research aims to obtain the insights of what are the major concerns for realizing the supply chain integration and how the process of it can better be improved in an effective way. The paper focuses on investigating the value created from information sharing by decreasing inventory level and the profit allotment based on the cooperation between supply chain partners. The basic elements for core partner to be motivated to advocate supply chain integration through information sharing are analyzed, and how the profit allotment between partners can effectively motivate the partners to be cooperative with each other are investigated.

The supply chain cooperative concept is defined according to the characteristics of different types of cooperation within supply chain with the view of cooperative game theory approach. Based on describing supply chain characteristics the business relationships between partners may be classified as cooperative or non-cooperative, and in each of the situations the benefits that can be obtained by individual partners might differ. In the context of supply chain cooperation the feasible business solutions for profit sharing between partners in a multi-level supply chain system may be classified as the globe optimized value solution, coordinating solution, cooperative solution, optimized cooperative solution. A graphic model with three dimensions is developed to describe the feasible solutions of profit sharing between core partner and other partners in three-level supply chain system, and the feasible sets of each type of the cooperative solutions are presented.

Based on the information sharing analysis by means of cooperative game theory approach the issue of how the interest conflict between the supply chain as whole and individual partners to be properly dealt with is also investigated. The mathematical model is developed for analyzing the framework of business solutions between supply chain partners, and together with the use of graphical model each of the cooperative solutions taking information sharing into account is described and discussed. A numerical illustration is presented as well.

The research findings show that in the process of realizing information sharing strategy within a supply chain each of partners must be motivated to active, thus the value created from the information shearing for the supply chain as whole needs to be properly allotted between partners to satisfy the interest of each partners.

Keywords: *Supply chain, Information sharing, Cooperative game theory, Value*

MANAGING INVENTORY WITH TWO SUPPLIERS UNDER YIELD UNCERTAINTY AND RISK AVERSION

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Yield uncertainty is becoming an important issue in inventory management as it tends to affect supplier alternatives and inventory options. In operations literature, yield uncertainty is customarily treated as a random variable. However, most of the studies on yield uncertainty are focused on single supplier case. Recently, Chopra et al. [1] consider a two suppliers model and investigate the importance of decoupling disruption and recurrent supply risk when planning mitigation strategies in a supply chain. In this paper, like Chopra et al. [1], we also consider a single-product setting in which a firm has two supply options: one is unreliable and cheaper and the other one is reliable but more expensive. The reliable supplier always delivers exactly what is ordered. Responsiveness of the reliable supplier allows the manager to place order after observing the response of the first supplier and yet receive supply in time to meet the demand. The capacity must be reserved at the reliable supplier and the firm can not order more than it reserved. The firm has to pay for each reserved unit even if the actual ordered quantity is less than the reserved quantity. We assume that the reservation cost and the prices of one unit at two suppliers are so that it is less expensive to buy from the unreliable supplier. We develop a cost model to determine the optimal order level and reserved quantity. Chopra et al. [1] study the problem from the point of view of a risk neutral situation as they consider only the expected cost not the variability of the cost. In this paper, assuming that the firm manager is risk averse, that is, (s)he is willing to accept some degree of increased expected cost in order to reduce the variability of the cost, we consider a trade off between the stochastic cost's expected value and its variance. With numerical examples, we show how the resulting strategies differ from those obtained in the standard (risk neutral) analysis. Computational results also demonstrate the effectiveness of dual sourcing strategy over the single sourcing strategy.

Keywords: *Inventory management, dual sourcing, risk aversion, supply uncertainty*

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GLOBAL SUPPLY CHAIN MANAGEMENT

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Introduction: During the last twenty years companies have witnessed a considerable expansion of supply chains into international locations (Taylor, 1997; Dornier *et al.*, 1998). This means that companies tend to source, manufacture and distribute all over the world. Research has identified many advantages of that: cost reduction, due to customs duty and trade concessions, low cost direct labour, capital subsidies, and reduced logistics costs in foreign markets (Ferdows, 1997), but also to exploit distribution channels, to access to overseas markets, to be closer to customers and to improve reliability. However global supply chains seem to be more difficult to manage than domestic supply chains (Dornier *et al.*, 1998). Among the main effects, there is a significant impact on inventories management. Global sourcing and manufacturing (i.e. off-shoring and/or outsourcing) mean longer lead times, difficulties in coordination and integration with suppliers, a more complex and risky transportation system. This could vanish the benefits of going global, e.g. due to higher inventories levels. On the distribution side, global firms face different markets with different demand profiles and again the logistical system – i.e. number and levels of warehouses, localization, transports - is more complex. Moreover infrastructural deficiencies in developing countries (e.g., transportation and telecommunications, inadequate worker skills, supplier availability, supplier quality, etc.) provide challenges normally not experienced in developed countries (Meixell and Gargeya, 2005). For these reasons, companies have always paid relevant attention to the choice of where and how to invest in extending their supply chains. This paper aims to analyse the extent of the adoption of global supply chains in the manufacturing industry. Specifically we aim to highlight the changes that have occurred in the last 6 years in the extent to which supply chains are managed on a global perspective. Moreover we want to identify which contingent factors can explain both the extent of adoption and the eventual changes occurred over time.

The main goal of this paper is to investigate the globalization of the supply chain of manufacturing firms and its relationship with contingent variables. Specifically the paper aims to contribute to the following issues:

1. Understand which are the global supply chain configurations, defined in terms of level of both sourcing and distribution at global scale, actually adopted by manufacturing firms across the world.
2. On a second perspective, since there is a common perception that the level of globalization of supply chains is increasing, we would like to test such assumption with actual data.
3. Once the configurations have been identified and their evolutionary trend has been described, we aim at gaining a deeper understanding of the impact of contingent factors on the level of globalization of the supply chain. Previous literature suggests that contingent variables should be able to explain differences in supply chain configurations. In particular, since previous literature analysis has provided evidence regarding variables such as company size and industrial sector, we focused our

analysis on globalization and localization of manufacturing, in order to investigate the effect of manufacturing configuration on the supply chain. We considered also company size in order to check for potential size effects.

In order to investigate the above research questions, data have been collected within the fourth edition of the International Manufacturing Strategy Survey, a research project carried out in 2005 by a global network (IMSS IV), and compared with those collected in 2001 (IMSS III). This project, originally launched by London Business School and Chalmers University of Technology, studies manufacturing and supply chain strategies within the assembly industry (ISIC 28-35 classification), through a detailed questionnaire that is administered simultaneously in many countries by local research groups; responses are gathered in a unique global database. In order to gain a longitudinal perspective, we compare data collected within two subsequent releases of the same research project, which are very similar, despite single respondents may not be the same. We consider this choice suitable, since our main goal is not to study individual firms, but rather to compare two similar samples, in the same industry and economic areas. Besides, a sub-set of firms participated to both editions of the research, thus allowing us also to investigate the same companies over time (strict longitudinality). The two samples, namely IMSS IV and III, consist respectively of 711 and 558 firms from 23 and 17 countries, with an average response rate of 34% and 12%.

The strictly longitudinal sub-sample consists of 71 European companies overall, among which only 59 provided enough data for our purposes.

The results of the paper provide evidence of the evolving adoption of global operations by several companies. However, it seems that not all companies are moving sourcing and distribution globally, but several seem to confirm their local attention to operations regardless of the globalization phenomenon. The paper also highlights some contingency factors that seem to explain the different behaviours. From one side there seems to be a strong relationship between the globalization of production activities and the globalization of the supply chain. Since we have considered only the globalization effect at plant level, this result arises the hypothesis that companies producing globally are managing all local activities on a global perspective. From another side, globalization of the supply chain seems to be strongly related to the country where the plant resides. This result is coherent with previous contributions in current literature regarding the effect of different environmental elements (e.g., import/export taxation) on the globalization of companies' activities.

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A MODEL OF QUANTIFYING THE INVENTORY VISIBILITY AND ITS USE OF ASSESSING THE EFFECTIVENESS OF RFID INTRODUCTION FOR INVENTORY MANAGEMENT

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When a specific warehouse is assumed for inventory management, the process of handling items in the inventory can be identified as follows: stocking (putting an item into the warehouse), repositioning (transferring an item between the places in the same warehouse), and delivering (taking an item out of the warehouse). In this paper, the inventory visibility is referred to as the level of certainty of each item's position during the item handling process, i.e., the accuracy in tracking of inventory. We propose a model of quantifying the inventory visibility and evaluate the effectiveness of introducing RFID (Radio Frequency Identification) in item handling process, as well as the benefit from the introduction.

Currently, RFID is considered as one of the breakthrough technologies to improve the inventory visibility. However, some managers are not convinced of introducing the RFID technology in their inventory as a substitute of the proven technologies, e.g. barcode systems. This is mainly because the reliability problem (e.g., tag identification errors) resides inherently in RFID systems and the managers are concerned about the undesirable performance due to the problem. We expect that their concerns can be resolved when an appropriate evaluation model for the effectiveness of the introduction is given, taking the reliability problem into account.

To quantify the inventory visibility, we first decompose the inventory to be analyzed into item-handling subsystems according to the process stated above, and identify the activities for tracking of inventory (including the facilities employed) at each subsystem. Then, the information visibility level of each subsystem is determined based on both the accuracy and the frequency of each activity related to the subsystem. To specify the visibility level, we use the entropy concept in information theory. The concept corresponds to our objective well because we focus on the certainty of item position in inventory. The accuracy of identification naturally influences the certainty of the item position while the frequency affects the visibility because information decays as time passes by without further identification. Lastly, the visibility of the target inventory is aggregated based on the visibility levels of subsystems.

With the proposed model, it is possible to quantify transparently the expected discrepancies between the physical inventory and the inventory records with regard to the different inventory management schemes. Hence, the managers can evaluate a projected inventory management system with RFID in a rational way and can conclude whether the system will satisfy the required level of the inventory visibility. Further, it is also possible to carry out the cost-benefit analysis in deploying the new system.

Keywords: *Inventory Visibility, RFID, Quantitative Model, Entropy*

A SIMPLE AND ACCURATE APPROXIMATION FOR THE ORDER FILL RATES IN LOST SALES ASSEMBLE-TO-ORDER SYSTEMS

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Assemble-to-Order (ATO) systems have received a lot of attention in research in the past few years. Assemble-to-Order systems are common in the computer manufacturing and telecommunications industry. New products are designed around interchangeable modules that are kept to stock, because it allows a high responsiveness in a highly dynamic market. An advantage of ATO systems is that a broad range of products can be delivered with only a moderate number of stock keeping units (and moderate stock levels). We focus on the business-to-business market and an example of typical products are professional printing systems by Océ Technologies, HP or Xerox. In general, the customer can select a product from a number of product groups or families, and the customer can adjust some components according to his preferences.

One important difference between our system and the systems that have been analyzed so far is that we analyze a lost sales situation in combination with deterministic lead times (ample servers). We believe that a lost sales assumption is much more appropriate in a business-to-business environment than the backordering assumption that is made in the majority of the ATO literature. This identifies a clear gap to which we contribute with this paper.

We study a single-location, multi-item inventory system for components that are produced to stock. These components are assembled into an end-product when a customer order arrives. We consider multiple types of end-products, where a fixed set of components is required for each end-product. Demands for end-products occur according to independent Poisson processes.

When an order for an end-product arrives, the stock of all required components is checked. If all components are on stock, the product will be assembled immediately and then shipped to the customer. If some components are not on stock, those components will be delivered via an emergency shipment; demand is lost for those components for the stockpoint under consideration. In the meantime, the components that are on stock are reserved for this order, and the end-product is assembled as soon as all components are available. Emergency shipments are applied because of the importance of a high delivery reliability in a business-to-business environment. Notice that demand is not lost for the customer because the end-product will be delivered, possibly with a short delay.

The inventory of each component is controlled by a base stock policy. Components are replenishment immediately after usage. It always takes a fixed amount of time to replenishment a component. The service measure of interest is the order fill rate, i.e., the percentage of orders for which all components can be delivered from stock.

In this talk, we present a simple, approximate evaluation rule of the order fill rates. This rule is based on a linear combination of the order fill rates in two extreme cases, viz. the so-called minimum and maximum demand coupling case. For the weights in this linear combination, we introduce a so-called demand coupling factor. The approximate evaluation is applied to a large test bed, and we show that the approximate evaluation is fast and accurate. Our approximate rule is rather general and we think that similar rules can also work for variants of the ATO system that we consider. These extensions might be investigated in future research.

Keywords: *multiple components, multiple end-products, basestock control, order fill rates, approximate evaluation*

ADAPTIVE DATA-DRIVEN INVENTORY CONTROL POLICIES BASED ON KAPLAN-MEIER ESTIMATOR

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In this paper, we develop a new adaptive *data-driven* algorithmic approach for stochastic inventory control models. In contrast to traditional stochastic inventory control models, we do not assume that the demand distributions are known explicitly as part of the input. Instead, we take a *nonparametric* data-driven approach with minimal assumptions on the true underlying demand distributions, requiring only distributions with finite mean. In particular, stocking decisions are made with no access to the true underlying demand distributions. Moreover, unlike many other data-driven approaches that are based on *historical demand*, we assume only to have access to past *sales data*, which can be thought of as *censored demand*. The new data-driven algorithmic approaches are based on one of the most well-studied tools in statistics, the *Kaplan-Meier* (KM) estimator for censored data. The KM estimator is used to create new adaptive data-driven stochastic inventory control policies that are conceptually very simple and computationally easy to implement. We study the theoretical properties of these policies and show that in some sense they are optimal, at least asymptotically. As a byproduct of the theoretical analysis, we obtain several new theoretical results on the asymptotic consistency of the Kaplan-Meier estimator. To the best of our knowledge, these results extend previously known work in the statistics literature. Extensive computational experiments demonstrate that the newly proposed policies outperform previously known policies.

The focus of this paper is on the *distribution-free newsvendor model with censored demand*. The newsvendor model is one of the core and most well-studied models in inventory theory. It is well-known that if one knows the distribution of the demand, it is optimal to order the *newsvendor quantile* that is defined by the ratio between the marginal costs of over ordering and under ordering. However, there has been relatively little work to study this model within a nonparametric data-driven framework. In the distribution-free newsvendor model with censored demand, repeated newsvendor stocking decisions are made over infinite horizon. At the beginning of each period, we decide how many units of supply to stock and only then do the stochastic demand and the respective linear holding and lost-sales penalty costs occur. The demands in different periods are identically distributed and independent of each other. However, their distribution is not known. In each period, we can only observe the resulting sales that in the event of stocking out (i.e., running out of inventory) provide only partial (censored) information on the actual demand in that period. The decision in each period, can depend only on the past sales history that consists of observations (samples) from the previous periods, some of which are possibly censored. Moreover, this stocking decision affects both the cost incurred, and potentially the quality of the observation in the current period. This gives rise to a complex model, in which one needs to balance between *optimization* and *learning* (or *exploitation* and *exploration*).

Extensive computational experiments suggest that the new policies converge for general demand distributions, and demonstrate that they outperform previously known policies. As a byproduct of the theoretical analysis, we obtain new results on the asymptotic consistency of the Kaplan-Meier estimator that extend existing work in statistics. To the best of our knowledge, this is the first paper to apply the Kaplan-Meier estimator within an adaptive optimization algorithm, and it is the first application to stochastic inventory control models. We believe that this work will lead to additional applications in other domains.

Joint work with Retsef Levi, Paat Rusmevichientong and James Orlin.

INVENTORY MANAGEMENT FOR SHORT LIFE-CYCLE PRODUCTS WITH STOCHASTIC DEMAND IN THE POST-EARLY SEASON

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Accurate forecasting of the demand for style and seasonal goods is a main challenge of inventory management for retailers. This is particularly true for the situation where retailers only have a single opportunity to place orders before the selling season. However, instead of developing more accurate demand forecasts, researchers have employed other strategies to tackle this type of inventory problem. In this paper we examine the inventory management strategies for short life-cycle products with stochastic demand using a 2x3 matrix comprising a forecast and a timing dimension. The forecast dimension categorizes forecast factors into either exogenous or endogenous variables. The timing dimension divides the time horizon into pre-season, early season and post-early season. By classifying current research into the 6 different entries of the proposed 2x3 matrix, we observe that there is a blank entry corresponding to research that treats forecast factors as endogenous variables in the post-early season.

On the one hand, research that treats forecast as an exogenous factor has been well conducted spanning the timing dimension. The newsvendor model and its many extensions have been extensively developed over the last half-century. Different strategies based on pricing models and return policies have been applied to address inventory management issues in the post-early season. On the other hand, research that treats forecast as an endogenous variable has always focused on inventory management issues in the pre-season period. In recent years some researchers have extended their studies to the early season period by using option and capacity commitment as mechanisms that allow for one additional order after early sales have been observed. Researchers have confirmed that forecast accuracy can significantly be improved after early sales have been observed. Therefore, the problem of demand mis-matching can be alleviated if additional orders are allowed.

In our study we make a breakthrough by proposing a multiple order replenishment environment for retailers during both the early and post-early seasons, even when the selling season is short. If a shortterm forecast based on realized customer demand can be accomplished, then inventory can be much better managed. We find that lead-time is not a key barrier. Instead, it is risk consideration that prevents suppliers from providing additional production opportunities. Many researchers have assumed that long lead-time is a necessity, which may not be true in reality. In fact, some practitioners in the fashion and computer industries have mastered the knowledge of filling orders in very short time periods, but they still practise long lead-times for production scheduling. Our study opens up a new direction in inventory management, one that can match uncertain demand much closer with reality.

Keywords: *Short life-cycle product; inventory management; stochastic demand; post-early season; exogenous/endogenous variables; risk*

A PICKUP SCHEDULING PROBLEM, AN EFFECTIVE HEURISTIC APPROACH

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Pickup scheduling problems are a particular case of routing problems transporting loads of various products between different locations. Problems related to pickup products consist of a fleet of trucks and a set of customer requests having in general different characteristics, mainly associated with the attributes of vehicle types and the nature of the loads.

A greedy type heuristic algorithm is presented that can solve problems with a relative large size, meeting real life problems. The paper is concerned with a variation of the pickup scheduling problem considering the compatibilities of products to be transported and the priority constraints induced by real life situations like customer importance, special load and unload conditions and load types. Focusing on the optimal pickup completion time, we take into consideration truck load balance. Indirectly a near-balanced distribution is performed.

A single-entry single-exit vertex and arc weighted, topologically ordered directed acyclic graph represents the transportation requests and the priority constraints. Each node is associated with a pickup location and with the corresponding loading completion time. Transfer times across pickup nodes are known in advance.

A fleet of non-identical trucks is available to serve the transportation requests, having in general different capacities and forbidding a truck to serve more customers than its capacity allows. Each truck can carry only a known subset of compatible loads and may have to visit some locations in a particular sequence depending on priority constraints, originating and terminating at central warehouses. Pickup locations have to be visited exactly once and by exactly one truck.

The next visited location at every stage and for every truck, concerning storage loading, must satisfy the following conditions:

1. The different transported product in every truck must verify the product compatibility requirements.
2. The subsequent loading of the products must conform to a predefined constraint so to facilitate the unloading completion to the housing terminal warehouse.

The heuristic approach consists of two phases. During the first phase a priority-ruled scheduling scheme is used to allocate a feasible set of loads to each truck. The selection procedure assigns repeatedly the maximum unallocated pickup load to the truck with the maximum free capacity. A backtrack procedure accomplishes a new selection each time an allocation should lead to insufficient use of capacities. The second phase uses a topological ordering of loads that have already been assigned to each truck to find the route with the minimum transportation completion time among all possible paths of the truck, satisfying concurrently the priority constraints.

The paper is completed with a detailed small numerical example of the proposed algorithm.

Keywords: *pickup scheduling, sequential loading, product compatibility, housing, minimum completion time.*

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AN ECONOMIC PRODUCTION QUANTITY (EPQ) FOR ITEMS WITH IMPERFECT QUALITY AND INSPECTION ERRORS

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The economic production/order quantity (EPQ/EOQ) model assumes that the result of a production process is of perfect quality. However a number of models have been proposed in the literature (e.g. Salameh and Jaber, 2000) that do not use this idealistic approach. This paper examines an optimal production/order quantity that considers imperfect processes. An inspection process is utilized to measure the defective proportion of the production lot.

Although most models assume inspection processes to be free of errors, in fact an inspection process is never perfect. A number of inspection plans that aim to remove defective items from a production lot have been proposed. A simple approach from the literature that incorporates misclassifications in inspection plans is used here. This means that an inspector may classify a non-defective part to be defective. He may also classify a defective part to be non-defective. Three types of costs are involved in this simple inspection process; the cost of inspection, the cost of type I errors and the cost of type II errors.

The paper extends the model of Salameh & Jaber (2000) by assuming that a lot is produced in a single batch and that the lot contains a random percentage of defectives that have to be screened out. The lot is inspected and screening takes place but the inspector may commit errors while screening. The probability of misclassification-errors is assumed to be known and defective items are kept as salvage items. Defective parts that are misclassified as non-defective and are returned by the customers are added to this salvage lot. The salvaged items are sold as a single batch at a lower price. The total revenue is the sum of the revenue from non-defective items and salvaged items. The total cost is the sum of the costs of setup, production, inspection, misclassifications and the holding cost. An optimal production quantity is computed that maximizes the difference between the total revenue and the total cost.

Numerical examples are provided that illustrate the solution procedure and compare the results to those of Salameh and Jaber (2000). This is then followed by a sensitivity analysis to gain further insights and to draw some managerial implications of the proposed model. Finally, the paper explores some immediate extensions to the work.

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IMPROVING "LEAGILE" SUPPLY CHAIN PERFORMANCE TO SATISFY ULTIMATE CUSTOMER: EXPERIENCE OF A POLISH DISTRIBUTOR

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Supply chains rather than individual companies compete in most markets, but in fast moving consumer goods in particular. The ultimate goal of these chains to satisfy the final customer and all chain members have to contribute.

However, not all customers are alike and consequently, they have different demands. For some price can be the order winner, whereas for others it can be something intangible as adding to lifestyle. Not all supply chains are organized in the same way as in some a limited number of vertically integrated firms cooperate, whereas in others players can specialize in certain processes in the supply chain. On one hand, the supply chains may concentrate on the increase of internal efficiency (eg. for stakeholders, owners, employees) through reducing and eliminating waste, on the other hand, they may focus on maximization of value delivered to customers. The first group concerns lean supply chains, the latter one is linked to the agile supply chains. In practice, the two extreme types could be combined in one successfully designed leagile supply chain.

Fisher (1997) combined these two observations in a simple framework: a 2x2 matrix with functional or innovative products sold through an efficient or a responsive chain. However, the basic underlying assumption of trade-offs between performance criteria is challenged and many talk about add-ons (Slack et al., 2004). Although not all performance criteria are always equally important (sometimes they are order winners, sometimes only qualifiers), they have to be met to some extent. How to organize to meet this mixture of objectives? A lot of confusion exists on what is the real message of lean and agile approaches. Some see lean as superior to mass (Womack et al., 1990), whereas others seem to treat it as mass (Mason-Jones et al., 1999) or see agile as superior to lean (Christopher, 2000) One problem with agile is that a living example as Toyota for lean is difficult to be traced.

In this paper we try to clarify some of the confusion around these approaches and hence make them easier applicable in practice. We do this by describing the role of a Polish distributor in its chain and the organization design of the company. Than we label its characteristics as lean and/or agile referring to the relevant literature. Consequently, we come up with a discussion on the content of the approaches not emerged from literature but empirically driven. This could clarify at least some of the confusion in literature. This discussion will also contribute to increased consistency in application of the principles from each of the approaches in everyday management practice.

Keywords: *leagile supply chain, supply chain performance*

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ON HOW THE ACQUISITION OF RECOVERABLE PARTS INFLUENCES THE PROFITABILITY OF SPARE PART MANAGEMENT FOR DURABLES

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In the management of spare parts OEMs often face a sharp decline in sales of spare parts when entering the post-warranty period of their products. The predominant reason for this effect is usually the high profitability of the after sales market which attracts competitors supplying spare parts at lower prices to the customer by use of alternative sources. This considerably reduces predictability of spare parts demand and thus poses a large challenge for the OEM. If the alternative source is repair of used or broken parts, an acquisition of those parts might lower competition and increase spare parts demand faced by the OEM. The purpose of this paper is to provide a case-based but simplified framework to draw insights from the acquisition of recoverable parts. We consider a two-stage supply chain, where an OEM producing durable products is obliged to satisfy any customer demand for spare parts he faces when components are broken. Independent repair shops are responsible for handling the repairing process in a corresponding area. There are two options to service the demand: either repair shops replace the component by a new part they order from the OEM or, if they have a formerly broken part (which they repaired before) available, they may use the recovered component. Servicing the customer leads to an inflow of recoverable parts at the repair shop. Repair shops earn a higher profit with repair and customers prefer those parts due to cheaper prices. Therefore, the model considers competition in supplying the customer with spare parts. On the other side, the OEM would prefer replacement parts but he has no direct control on demand which they might indirectly regain by introducing a buyback fee. Further on, due to the higher volume of returning parts, this would enable opportunities for the OEM to recover these parts on a higher level, i.e. through remanufacturing and thus reducing production/procurement of new parts. The main contribution of this paper is to elaborate the important effects of procuring recoverable items on volume and variability of spare parts demand faced by the OEM by using simple deterministic and stochastic models and to outline the impact of different parameters (i.e. recovery costs at each stage and buyback fee effect) on the profitability of spare parts management.

Keywords: *Spare Parts Management, Inventory Management, Product Recovery*

A FRAMEWORK FOR ENHANCING SUPPLY CHAIN INTEGRATION BETWEEN CUSTOMERS AND SUPPLIERS

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In order to survive in the competitive environment today, companies involved in business-to-business –markets are forced to create partnership arrangements with their most important customers. These partnership arrangements usually include close integration between the customers and suppliers in many areas, like research and development, supply chain management, information technology and marketing. However, finding the integration points that bring the biggest benefits can often be very laborious and time-consuming.

In this paper, we focus on supply chain integration between suppliers and customers and propose a framework that enables decision makers to analyse, prioritise and select the areas for integration and cooperation systematically and effectively. In addition to selecting the integration points, the framework is used for setting joint targets and joint action plans in order to achieve the identified joint benefits in areas like for example inventory management. The proposed framework is an effective tool for customer-supplier integration as it helps both the customer and the supplier understand the objectives, constraints and processes of the other party and thus increases the possibilities to achieve consensus on the way forward.

The proposed framework relies heavily on the utilisation of advanced decision support tools in order to enable effective execution. Group decision support systems (GDSS) are utilised for idea generation, analyses and creating consensus while tools like the Analytic Hierarchy Process (AHP) are used for setting priorities. GDSS technology supports group work by eliminating communication barriers, offering the group different tools and managing the use of time as well as by systematically handling meeting items. The aim of a GDSS is to reduce the process losses associated with conventional group work; these are, for example, disorganized and unfocused activity, the dominance of one or a few members over the group and the consequent inhibition of others and the social pressure to conform. AHP is a multi-objective, multi-criteria decision-making approach that employs a method of multiple paired comparisons to rank alternative solutions to a problem formulated in hierarchical terms. It is a technique for converting subjective assessments of relative importance into a set of weights. The pair-wise evaluation of AHP are used here to set relative weights for the criteria of the framework.

The utilisation of the proposed framework is demonstrated with an illustrative example in a process industry context.

INTERNATIONAL COMPARISON OF JIT PRODUCTION, SUPPLY CHAIN MANAGEMENT, AND MANUFACTURING PERFORMANCE

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This paper aims to explore the relationships among JIT production, supply chain management, and other manufacturing practices, and compare the relationships and the impact on manufacturing performance to find out the commonalities and differences in the way to high performance manufacturing among regions.

Practices regarding JIT production are measured in terms of the following scales:

Daily schedule adherence; Equipment layout; Just-in-time delivery by suppliers; Just-in-time link with customers; Kanban; Repetitive nature of master schedule; Setup time reduction; Small lot size; Synchronization of operations.

Supply chain management could be evaluated by the following multi-item measurement scale:

Coordination of Plant Activities, Stability of Demand, Supplier Lead Time, Supply Chain Planning, Trust-Based Relationship with Suppliers.

Other manufacturing practices include human resource management, theory of constraints, quality management, total preventive maintenance, technology development, new product development, and manufacturing strategy, which are interrelated with JIT production and supply chain management.

Under the High Performance Manufacturing project, survey data have been collected from machinery, electrical & electronics, and automobile manufacturing companies located in the USA, Europe (Austria, Finland, Germany, Italy, Sweden), and Asia (Japan and Korea) since 2002, which is used to test the reliability and validity of each measurement scale. Some of measurement scales cannot pass the reliability and/or validity tests even after irrelevant question items are deleted. The remaining measurement scales and performance indicators are used for the analysis.

The relationships between JIT production and supply chain management and other manufacturing practices and their impact on manufacturing performance is analyzed by using canonical correlation analysis, because they all are multivariate, and the results from respective regional samples are compared.

The comparative analysis reveals important differences in the relationships among manufacturing practices. Much closer relationships among them except new product development are found in Asian companies than in European and US companies. On the other, manufacturing performance strongly depends on supply chain management, JIT production, quality management, and total preventive maintenance in Asian companies, while new product development, technology development, manufacturing strategy, and supply chain management have impact on some dimensions of manufacturing performance in European and US companies.

Keywords: *JIT production, supply chain management, manufacturing performance, empirical research*

DECISION MAKING SUPPORT FOR PRODUCTION MANAGEMENT BASED ON POLICY LEARNING APPROACH

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In the economic environment which changes suddenly, in order to correspond to a customer's needs quickly, a company always has to secure many stocks. Therefore, a company cuts down waste such as extra stock and physical distribution cost, and needs a mechanism which send as quickly and cheaply as possible a product. So, supply chain management attracts a great deal of attention. We regard mass customization as dispersion of order from maker to supplier, and treat maker's order, that is demand of supplier as probability variable. And, we propose production planning without a shortage of stock using solution algorithm under the condition that we consider production management.

In recent years, the industry pushes forward reduction in cost, induction of foreign capital, competition promotion between suppliers and so on. It becomes very important in future to remove waste of the production business and to realize needs of an individual customer and the conformity property to a change of a market. In particular, we must satisfy the variety of customer specification in product and service, without dropping the productive efficiency in mass customization.

On manufacturing of such "customized product", load leveling of production becomes very difficult because they have to manufacture order of customers based on each specification. At load leveling, we had to order from supplier and manufacture in final line of a car manufacturer. Then a productivity decreases, finished goods in stock increase, and it becomes difficult to deal with customer specification.

There have already been some manufacturing strategies for mass customization. On the other hand, the design method of product planning and management system for it is not established. Under the precondition that supply lead time which supplier demands is longer than production lead time which manufacturers product, as product planning and management system for mass customization, Make-to-Order management system which starts manufacturing after receiving an order has been applied for a variety of customer specifications. However, it's not often cases that supply lead time becomes longer than production lead time. Therefor manufacturers have to supply purchases and start manufacturing before they receive an order from customers.

We first describe a design procedure of the whole production planning and management system for implementing mass customization. Secondly, we define production planning and management system as the stochastic environment to find production plan minimizing manufacture and inventory cost under both unfulfilled supply order constraint and production constraint. Next we show how to get practical and effective solution to the problem.

Keywords: *Production Management, Manufacture, Inventory Cost, Stochastic Environment*

IMPROVING SPARE PARTS SUPPLY CHAIN PERFORMANCE THROUGH PART CATEGORIZATION

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Spare parts inventory control is a complex problem and in most cases part categorization is needed to create a manageable number of control groups to focus inventory management efforts more effectively. Usually multi-dimensional or multi-criteria classifications are used, and there are several examples of classification schemes available in the literature. When taking into consideration that a supply chain consists of several parties the complexity still increases. Thus, in addition to internal inventory control factors, external factors such as supplier performance and customer behavior and related demand patterns affect the controllability of the various parts.

In the paper we try to expand existing classification schemes that cover only one part of the supply chain into a decision tool covering three sides of the chain: a focal company and its internal processes, supplier and supply processes, and customer and demand processes. The analytical complexity created by the expanded view is reduced by creating two separate links: internal and demand process link, and internal and supply process link are analyzed separately, and then the most relevant factors of each link are combined to create the relevant part categories for analyzing the supply chain performance. Internal and demand process link uses part value, demand volume and demand variability factors to create seven specific control categories. Internal and supply process link uses supply availability, lead-time and lead-time variance to create four categories.

The categorization scheme is tested in a large international company for improving its spare parts supply chain management. The spare parts supply chain is analyzed with these factors in terms of supplier performance, internal planning issues and demand management. The paper presents root cause analysis of performance deficiencies in each category and derives recommendations for the case company. The analysis can then be directly used by the responsible manager in practice, for example supplier performance related root causes and recommendations can be taken into use by sourcing and purchasing managers. Finally, it is discussed how widely the insights from the case experience can be generalized towards developing a generic management tool for such a complex situation.

***Keywords**: Spare parts, supply chain, inventory management*

INVENTORY CONTROL OF SPARE PARTS IN THE FINAL PHASE

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Nowadays, due to innovation, the lifecycle of finished goods have shortened dramatically. The impact of this shortening can often be problematic for service. End of life phase of spare parts starts immediately after production stop. End of life inventory problem deal with final ordering quantities in this phase. In all previous study, just repair policy is considered and alternative policies are left out of consideration. To fill in this gap, the classical final order problem is extended by including the possibility of alternative service called swapping policy. The Extended Final Ordering Problem (EFOP) reads as follows: "For a spare part used for service, find the final order quantity and the switching time to alternative policy that minimizes the expected total cost function over a predefined horizon given the possibility of switching to an alternative service policy before the end of the end-of-Life horizon"

Considering a non-homogenous Poisson process, as it is shown to be appropriate to represent the behavior of the final phase demand behavior, we develop a dynamic programming problem to find optimal solution. We assumed that all costs are exponentially discounted to the beginning of the horizon. Even though this assumption makes the problem more complicated but it is essential since in real world price erosion of the spare parts has a promising effect.

RECONFIGURATION AND RESEQUENCING IN MIXED-MODEL SUB-ASSEMBLY LINES UNDER CONSIDERATION OF RESTRICTED DECOUPLING BUFFERS: AN ANALYSIS OF AN OEM IN THE AUTOMOTIVE INDUSTRY

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Diversification via customization of mass-produced goods, so called mass-customization (Pine, 1993, S. 8), is the key to success for companies producing consumer durable goods in a many branches of industry, e.g. in the automotive industry. In this context the positioning of the customer order decoupling point is of major interest (Ohlhager, 2003). Production-on-stock would lead to a high level of inventory that causes high opportunity costs and obsolescence costs under consideration of short product life cycles. Therefore, innovative process improvements e.g. postponement and the installation of mixed model assembly lines have been developed to enable assembly-to-order production (cf. Bukchin, Dar-El & Rubinovitz, 2002).

Existing planning approaches (for an overview see Boysen, 2005) seem to be only partly applicable for sub-assemblies and 1st tier suppliers. Our research question is to develop a production planning concept designed for mixed-model sub-assembly lines by adapting a hierarchical planning system (here Boysen, Fliedner & Scholl, 2007). Afterwards we identify the major restriction for efficient solutions: the decoupling buffer.

Why can existing planning approaches not generate total efficient solutions?

To solve problems caused by variants modularisation of the finished goods is a common tool. In the automotive industry about 60 percent of the product's value is generated in sub-assemblies (Holweg & Pil, 2004, S. 137). Sub-assemblies (or 1st tier supplier) have to deliver these modules in sequence to the main line and to deal with the complexity of variants with small decoupling buffers (cut down by lean production (Merengo, Nava & Pozetti, 1999, S. 2835)).

The following steps are integrated in our production planning system (see Figure 1):

Due to the lean connection to the main line the steps Master Production Scheduling and Sequence Planning aren't applicable for sub-assemblies. Therefore product mix and sequence can differ from shiftto-shift totally. Reconfiguration has to be done on weekly bases to conquer these short-time product mix differences. Remaining inefficiencies will be improved by a short-term resequencing algorithm. Another target criterion is high stability of a line balancing against product mix scenarios. The nervousness against different product mixes will be assessed in a simulation model. The proposed planning approach will be tested by an imperial illustration example (sub assembly line now planned at an OEM). To show the effects

and potentials of our approach we use the results of a simulation. Additionally we want to show which buffer size for resequencing is economically optimal for this illustration example.

The described planning approach should enable OEMs and 1st tier suppliers to produce modules more efficiently, which finally will lead to a reduction in production costs. Moreover the new approach in planning systems will support lean structures (smaller invests) and high flexibility (fast and efficient adaptation to changes).

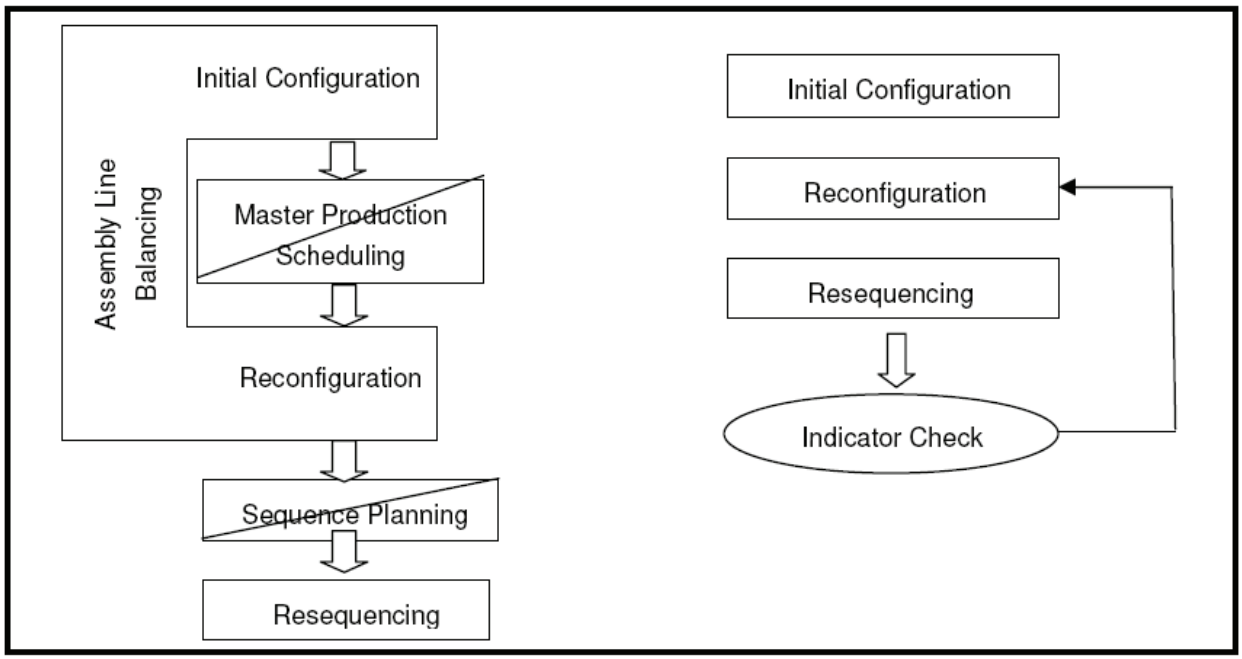

Figure 1 – Hierarchical Planning System Sub-Assembly Planning System (Adapted Boysen, Fliedner & Scholl, 2007)

Keywords: *scheduling, mass customization, sub-assembly line balancing*

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A GENERAL INVENTORY FRAMEWORK FOR INVENTORY INACCURACIES IN A DECENTRALIZED SUPPLY CHAIN: IMPACT OF THE RFID TECHNOLOGY

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One of the implicit assumptions considered in the majority of investigations performed in the area of inventory management is that the physical flow of products that passes through an inventory system as well as the associated information flow are free from defects, i.e. for a given type of product, the quantity received matches exactly the quantity ordered or there are no errors occurring during the data capture process such that the level of the available inventory shown by the information system corresponds exactly to the physical quantity available. However, various factors can create a difference between the expected and the effective physical and information flows and perturb the synchronized evolution between these two flows. The performance of such inventory systems whose flows are disturbed by defects can be improved by using advanced product identification and data capture technologies such as the RFID (Radio Frequency IDentification) technology. This paper deals with the evaluation of the deployment of the RFID technology by considering its impact on inventory inaccuracies. We first give an overview of potential errors that may occur within an inventory system. Then, we propose a general framework to model the impact of errors and we provide analytical optimal solutions for both centralized and decentralized supply chains. Then, we evaluate the performance improvement enabled by the RFID technology on such inventory systems.

Keywords: *Inventory management, errors, inventory inaccuracies, Newsvendor problem, product identification and data capture technology, RFID technology.*

A PRODUCTION/REMANUFACTURE EOQ MODEL WITH RETURNS OF SUBASSEMBLIES MANAGED DIFFERENTLY

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The production, remanufacturing (repair) and waste disposal model has been receiving increasing attention in recent years. The growing concern towards the environment by customers and governments forced manufacturers to consider options such as recycling, reuse, refurbishing, and remanufacturing. The available studies in the literature consider a production environment that consists of two stocking points; the serviceable stock, which is for production and remanufacturing (repair), and the returned (repairable) stock, which is for collecting used (returned) items to be recovered (e.g., repaired, remanufactured) in the serviceable stock. Models in the literature did not consider the disassembly process of used items (returns), where these items are disassembled into components that are tested for their quality and only those considered acceptable are pushed in the reverse flow. In addition, these studies assumed the ratio of the total remanufactured units to the total newly produced units fixed at a value, with this ratio representing the return rate. Furthermore, these studies did not consider the ordering policies for materials and components by the production/remanufacturing system from its suppliers.

In this paper, a production/remanufacturing inventory model for a single product that requires components to be supplied by several tier-1 suppliers, where each supplier supplies one or more types of components. It is assumed that used items of a product are collected at a fixed return rate and are disassembled into components that are tested for their quality. Accordingly, sorting is performed where returned items are segregated into different subassemblies. Poor quality subassemblies (of different components) are disposed. Only subassemblies (of components) with acceptable quality are pushed in the reverse flow to be used either in production or in remanufacturing. Here, the disassembly process is considered as an internal supplier that supplies the same types of components as all tier-1 suppliers. Consequently, each subassembly has a return rate different from the remanufacturing/production ratio, and subsequently, each subassembly has its own inventory control parameters. For the remanufacturing process to start, a sufficient amount for each subassembly is to be collected. Therefore, for each subassembly, two main strategies are considered. The first is a pure remanufacturing strategy, where the subassembly's return rate is either equal to, or larger than the remanufacturing/production ratio. This strategy results in a sufficient amount of returned subassemblies ready to be remanufactured. The second strategy is a mixed strategy of ordering and remanufacturing activities, where the return rate of a subassembly is less than the remanufacturing/production ratio. This strategy results in an insufficient amount of returned subassemblies, which has to be completed by ordering newly produced subassemblies. This paper investigates the conditions under which each of these strategies is optimal. Numerical results showed that there exists an optimal remanufacturing/production ratio, which is less than the return rate, where inventory decisions regarding the subassemblies either follow a pure remanufacturing strategy or a mixed ordering and remanufacturing strategy. Our results also show that it may be more meaningful to consider a return rate that is price and quality dependent.

Keywords: *EOQ, Production/Remanufacturing, Subassembly, Reverse Logistics, Price/Quality dependent return rate*

ON THE ALIGNMENT OF LOT-SIZING DECISIONS IN A REMANUFACTURING SYSTEM IN THE PRESENCE OF RANDOM YIELD RISK

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In recent years, closed-loop supply chain management has emerged as an important research area due to the tendency of stricter environmental regulations in industry such as the EU directives on waste electrical and electronic equipment (WEEE) and on end-of-life vehicles impose. Furthermore, the awakening of the economic attraction of recovering products rather than disposing them of led to a rising interest in this form of management.

The closed-loop supply chain perspective is an extension of the common supply chain concept which widens the scope of the chain beyond its natural end (i.e. the customer) since it rejoins all actors also in the opposite direction. It thereby includes the transport of wrappings, rejected products (i.e. for breakdowns or because of warranty expiration) or those products which have simply reached the end of their useful life-cycle from the customer back to the manufacturer. Within this research area, the sustainability plays a great role in terms of developing strategies on how to handle these backward flows efficiently. In order to achieve this objective many companies have extended their supply chain by the promising strategy remanufacturing. Within this strategy the returned products are disassembled to obtain the components contained therein. Since these components can not guarantee an as good as new status because of wear or detriment, the subsequent process of remanufacturing ensures their full functionality. Afterwards, these components can be reused for the assembly process of the manufacturer's products. Hence, the manufacturer is able to establish a second and less cost intensive opportunity of procuring all required components for their final products next to the option of producing all components newly.

The considered remanufacturing system can be modeled as a multi-level inventory system, whereas this contribution focuses on balancing the trade-offs between all relevant fixed and holding costs at each level. The fact that not only one option of procuring components is available for such a system complicates the determination of lot-sizes as well as possible stochastic influences on certain parameters. While in reality several parameters such as the demand for products by the customers or the return rates of old products from the customers are not known in advance, this contribution fixes those parameters to constant and deterministic values. Nevertheless, the disassembly process is regarded to be stochastic which reveals itself in a non-deterministic yield rate, i.e. the number of components obtained by disassembly is uncertain. This paper presents several heuristic policies on how to assess the lot-sizes at each inventory level within this environment. Common to all policies is that they determine the required parameters such as the disassembly cycle length and the number of manufacturing and remanufacturing lots per cycle by analyzing the overall inventory system and its relevant costs using the commonly known average cost approach. Finally, a numerical study compares the heuristic performances for different yield rate distributions.

Keywords: *Reverse logistics, remanufacturing, lot-sizing, disassembly, stochastic yields*

A CRITICAL APPRAISAL OF INVENTORY MANAGEMENT SYSTEM OF A MANUFACTURING INDUSTRY AND TWO EDUCATIONAL INSTITUTIONS

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In modern competitive world, one of the burning problems of every business, industry and service (Educational) is that of cost control and cost reduction. An all-pervasive effort for cost control and cost reduction from 'A to Z' is of paramount importance for the survival and growth of every industrial enterprise/ service organization. Therefore, an intelligent inventory management as a scientific device for controlling inventory cost and eliminating wastage is the need of the hour. Inventory management is responsible for planning and controlling inventory from the raw material stage to the customer. Since inventory either results from production or supports it, the two can not be managed separately and therefore, must be coordinated. Inventory must be considered at each of the planning levels and is thus part of production planning, master production scheduling and material requirements planning. The facts highlight the importance of the efficient and effective use of materials particularly in the present time of credit squeeze and unstable market conditions. Unlike other techniques, such as rationalization, work reorganization, productivity device, etc., inventory management does not involve any human factor, as it concerns itself not with men but with inventories. Accordingly, while other methods have to encounter resistance or reluctance of workers, inventory management can secure rich dividends much more easily and without inviting any such resistance and this is why modern management has started taking great interest in 'Inventory Management'. In this paper I would discuss the Inventory Management system followed in Government of India's three National importance organizations; viz, a Large Mining Organization and two Educational Institutions. The paper is based on a case study of the organizations in question and includes functioning of these organizations and also highlights the various problems being faced within these organizations. This study addresses the overall inventory management system followed at these three organizations. The study brings out the detailed analysis of inventory management system followed in the above organizations, the observations, issues and valuable suggestions. This case study would be practically helpful to the professionals for better understanding of the latest trends in the field of Inventory Control and implementation of suitable strategies wherever needed as per the local needs.

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RESEARCHING AND IMPLEMENTING INVENTORY MANAGEMENT SYSTEMS IN COMMERCIAL FIRMS: 40 YEARS OF EXPERIENCE

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The author has been researching, as well as helping to implement, inventory management systems in association with variety of firms over the last 40 years. This paper traces some of the interesting changes that have taken place in both the inventory planning tools available and the receptivity of managers in North American firms to using these tools over this period. We also draw conclusions about the challenges that remain in furthering the use of these tools in the future.

THE SELECTED DETERMINANTS OF THE POSTPONEMENT CONCEPT IN SUPPLY CHAINS OF MANUFACTURING COMPANIES: AN INTERNATIONAL STUDY

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The manufacturing companies constitute important central nodes in supply chains where almost all physical flows are concentrated. They occupy leading positions and perform main coordination activities in order to reach predefined goals. The manufacturing companies are fundamental links when selecting and implementing a postponement concept in their supply chains.

Postponement is the operating concept which aims at delaying activities until a customer's order has been received. The growth of interest in the postponement concept partially results from the increased demand for customized products. In order to enhance product offerings, many manufacturers are altering their supply chains to be more competitive towards the market rivals, responsive for the customers and cost-effective in performing organizational activities. One of the central issues, often raised in literature, is the identification which logistics operating contexts favour postponement.

This paper identifies and analyzes the selected decision determinants of the application of postponement concept in the supply chains of manufacturing companies. On the basis of literature review a number of variables were identified and selected being relevant for the application of the postponement concept. In order to conduct empirical research two questions were raised, namely:

> RQ1: what factors determine the practical application of the postponement throughout the supply chains of manufacturing companies?
>
> RQ2: what is the impact of the selected factors on the implementation of the postponement concept in the supply chains of manufacturing companies?

In order to investigate the questions a research methodology framework was developed and a necessary statistical analysis was performed. Data for the analysis has been collected from the survey carried out by researchers from several countries in Europe, North America, Asia and Africa among 861 companies between years 2005 and 2007. The main research instrument used for this research was a questionnaire developed by the Global Manufacturing Research Group (GMRG) and consisting of several sections examining the main fields of companies' activities. The whole questionnaire contains several hundreds of variables and allowed to create the data base of extremely rich informative value.

The conclusions obtained through the analysis were a basis of developing an initial research model showing the factors influencing the practical application of the postponement concept throughout the supply chains of manufacturing companies.

Keywords: *Postponement, supply chain, manufacturing companies*

STATIC VERSUS DYNAMIC SAFETY STOCKS IN A RETAIL ENVIRONMENT WITH WEEKLY SALES PATTERNS

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Sales in retail environments typically follow a weekly pattern having high sales at the end of the week and low sales at the start of the week. In this paper we compare two different ways of setting safety stock norms in a retail environment with weekly sales patterns. The first option is to set a single safety stock norm, which is constant thoughout the week. The second option is a safety stock norm which is dynamic and depends on the weekday. The inventory is controlled periodically and a lost sales environment is assumed. We study the impact of the dynamic safety stock on both the average inventory level and the workload balance, since earlier research has shown that retailers aim to smooth the workload which results from the inventory replenishment orders. We use a full factorial experiment and simulation to evaluate both inventory replenishment strategies.

Keywords: *Retail, Inventory, Replenishment, Dynamic, Weekpattern, Safety stock*

SAFETY STOCK OR SAFETY TIME: COPING WITH UNRELIABILITY IN ADVANCE DEMAND INFORMATION AND SUPPLY

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Advance demand information (ADI) can improve the performance of production/inventory systems (Karaesmen et al 2004). This might significantly increase the performance of industries like the food processing industries due to the fact that the processes are tightly coupled and little inventory is held compared to the production speed. A product in the food processing industry often flows through multiple departments and the plan of a demanding department, for a period (e.g. one week), is the input for the plan of a supplying department. In these systems perfect ADI is assumed, which is unrealistic for two reasons: plans are changed and machines break down. To cope with these variabilities safety stock or safety time is needed to smooth production. This paper investigates the optimal level of safety stock under different levels of unreliable ADI and different levels of supply and demand uncertainty.

Our inspiration stems from a case study at a can factory that supplies to a packaging department in the food processing industry. The case showed that variable production outcomes and the level of uncertainty of the ADI influence the need for safety stock. Due to variability in the production outcomes the shop floor manager of the can factory is not always able to deliver the orders of which he has ADI. Secondly if the advance demand information becomes less perfect and orders or volumes of orders are changed over time the delivery performance of the department is reduced even more. In practice this raises questions such as “What amount of safety stock should we keep to be able to deal with supply variability, demand variability and unreliable ADI?” So far the problem of the combination of uncertain supply, uncertain demand and unreliable ADI has not been addressed. Wijngaard (2004) showed that, when supply is stable, the effectiveness of ADI depends on variability and flexibility. In the case of highly variable demand ADI is more effective than in the case of stable demand. In an inflexible (highly loaded) situation inventory is necessary but it dampens the effect of advance information (Wijngaard 2004, Karaesmen et al 2004). The performance of a system improves if the variability of supply lead times is reduced (Karaesmen 2003) and if customers place orders further in the future (Gallego and Özer 2001). Kunnumkal and Topaloglu (2008) showed that the reduction of variability of supply lead times helps to reduce the safety stock and result in cost savings.

Based on the insights and real life data on production variability and order changes from this case we construct a simulation model that describes the interplay of uncertain supply, uncertain demand and unreliable ADI on the need to keep safety stocks. With the simulation outcomes and the insights from the case we will contribute to theory by describing the impact of unreliable ADI, supply variability and demand variability on the need to use safety stocks to achieve a required level of delivery performance.

Keywords: *food processing industry, advance demand information, limited storage, inventory policy, safety stock, simulation.*

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OPERATIONAL PERFORMANCE OF AN EMERGENCY ROOM (ER): TRADE-OFFS IN SPEED, INVENTORY LEVELS, AND RESOURCE UTILIZATION

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This paper, using detailed time measurements of patients, examines three facets of an Emergency Room's (ER) operational performance: (1) Effectiveness of the triage system in reducing the patient lead-time and its conformance to stated triage standards; (2) Factors influencing ER's operational performance in general and the trade-offs in speed, inventory levels (that is the number of patients waiting in the system), and resource utilization in particular; (3) The impacts of potential process and staffing changes to improve the ER's performance. Specifically, four proposals for streamlining the patient flow are discussed: establishing designated tracks ("fast track" "diagnostic track"), creating a "holding" area for certain type of patients, introducing a protocol that would reduce the load on physicians by allowing a registered nurse to order testing and treatment for some patients, and, potentially and in the longer term, moving from non-ER specialist physicians to ER specialists. The paper's findings are based on analyzing the paths of 1095 patients between November 8-28, 2004 and 798 patients between March 13-26, 2006 in the Emergency Room of the Medical Center of Leeuwarden (MCL), The Netherlands. These observations were complemented by interviews with hospital management and staff that also validated the findings presented here. Using exploratory data analysis the paper presents generalizable findings about the impacts of various factors on ER's lead-time performance and shows ways for potential improvements.

Keywords:
Emergency care, Services, Capacity and Lead Time Analysis, Work-in-Process Inventories, Exploratory Data Analysis.

INVENTORY AND PRODUCTION MANAGEMENT IN CONSTRUCTION INDUSTRY – AN INTRODUCTION

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Construction Industry can and have been criticised for high waste of construction materials (plasterboards, windows, doors, toilet equipments etc, even organised thefts must be suspected); low quality (e.g. mould in new houses); very conservative management and also conservative trade unions. All this ending up and creating low efficiency. Investigations show that the Construction Industry has a lower productivity and efficiency than the ordinary manufacturing industry.

We show a short overview of the administrative systems used in Construction Industry (in the Nordic countries). Traditional ERP-systems (like SAP/R3, Oracle etc) are not used in the construction processes. Planning and scheduling of a construction project is to a high extent still done without help from a computer system (compared to ordinary manufacturing companies).

We present and discuss arguments why traditional ERP-systems not are used; e.g. a traditional work centre does not exist in a Construction project!? We then argue how a construction project should be notified, in what stages; and what in what stages of the project. Such that plans for purchase, supply and other necessary resources can be created; such that the "critical line" continuously can be followed, studied and overruns avoided.

Necessary ingredients are ***prescriptions*** (e.g. how a wall is built from plasterboards, which is not the same but something similar to 'routings' in traditional manufacturing); ***tasks*** (e.g. building an inner wall at a special work location); ***resources*** (people and machines with special skills that perform the different tasks); ***items*** (construction materials, a task to be performed requires resources, items and tools). For the tasks immediate predecessors must be determined. 3D-presentations are necessary and the work locations, ***place***, are much more important and necessary than in a traditional ERP-system. Subcontractors are much more common also compared to traditional ERP-systems and a resource that must be well considered in the planning and scheduling of the construction project.

3.
MATHEMATICAL MODELS OF INVENTORIES

INVENTORY CONTROL IN A TWO-ECHELON DUAL-CHANNEL SUPPLY CHAIN WITH SETUP OF PRODUCTION AND DELIVERY

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Retailer is a traditional retail channel in supply chains. However, recently, internet made direct shopping easy, and it has become an important retail channel. Then, dual channels are becoming popular in supply chains. In the dual-channel supply chains, customers can change the channel to buy goods, and dual channels could mean more shopping choices and price savings to customers. To traditional retailers and manufacturers, however, the implications for their strategic and operational decisions are not all that clear. In considering the problems, traditional supply chain models are not sufficient for developing insights into the equilibrium performance of such supply chains. Then, some models to answer the above questions have been developed. Dumrongsiri et al. [1] develop a dual-channel supply chain model where a manufacturer sells the same product to a retailer as well as directly to consumers and consumers choose a channel to buy the product accordingly. An exact analysis leads us to conditions for dual channel equilibrium. Further results show the effect of demand variability on the supply chain structure, and they show that adding a direct channel will increase the total profit if it is feasible. However, in considering the profit, they have never considered the control of inventory at each channel. For the problem, Chiang and Monahan [2] presented a two-echelon dual-channel supply chain model in which stocks are kept in both a manufacturer warehouse and a retail store, and a one-for-one inventory control policy is applied. They define the total cost that consists of inventory holding costs and lost sales costs, and shows some insights from the results of numerical calculation. In the control policy, production stops when the inventory position at manufacturer reaches to the upper limit but it starts again just after the inventory position decreases from the limit. Also, delivery to retailer stops when the inventory position at retailer reaches to the upper limit, and it starts again just after the inventory position decreases from the limit. It may leads to increase the number of setups to produce and deliver. Therefore, in this paper, we propose a control policy to decrease the number of setups of production and delivery and to decrease the total cost that consists of inventory holding costs, lost sales costs, and setup costs of production and delivery in a dual-channel supply chain with setup of production and delivery. In the supply chain, the product is available in two channels and the system receives stochastic demand from customers. The demand of retail customers is met with the on-hand inventory at retailer while the demand in the Internet-enabled channel is fulfilled through direct delivery with the on-hand inventory at manufacturer. When a stockout occurs in either channel, customers will search and shift to the other channel with a known probability. As operational measures, the total cost that consists of inventory holding costs, lost sales costs, and setup costs of production and delivery is considered. Based on Markov analysis, the total cost is calculated, and numerical calculations show the effectiveness of the proposed control policy.

Keywords: *inventory control, dual-channel, supply chain, setup*

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RISK AVERSE PRICE SETTING NEWSVENDOR

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Research on newsvendor models with respect to quantity decisions has a long tradition in the operations management field. However, empirical observations as well as experimental findings state that the actual quantity ordered deviates from the optimal order quantity suggested by the newsvendor model (Schweitzer and Cachon, 2000; Brown and Tang, 2004). A possible explanation for these deviations is the objective function used by the inventory manager. Traditionally, the decision maker in the newsvendor model is assumed to maximize the expected profit implying risk neutral behavior. Following this argument, research on risk averse newsvendor models with different objective functions has become an important stream. For example, Jammernegg and Kischka (2007) use a convex combination of conditional expected low and high profits as objective function, while Lau (1980) maximizes expected utility of total profit.

On the other hand, including pricing as a second decision has become another important stream of research in the meanwhile (cf. Petruzzi and Dada, 1999, for an exhaustive review). To include pricing as a second decision variable, the demand functions used in that kind of models are traditionally divided into a stochastic and a deterministic pricedependent part, and the two parts are generally combined either in an additive or a multiplicative way. The objective is maximizing expected profit, which, again, implies risk-neutral behavior.

In our work, we combine those two streams by considering a risk averse newsvendor, who simultaneously decides on price and the ordering quantity. Agrawal and Seshadri (2000) is the first work combining risk averse decision making in a price setting environment. They study both additive and multiplicative price dependent demand models, where the newsvendor's objective function is an increasing concave utility function. However, using utility functions induce practical challenges, specifically, “specifying the decision maker utility function and determining related parameters are not easy” (Chen et. al., 2007). Thus, we use as a coherent measure of risk the conditional value-at-risk (CVaR) to include risk behavior. In our work, we analyze the price setting newsvendor model including the CVaR in the objective function and illustrate our approach with numerical examples.

Keywords: *Inventory, Newsvendor, Pricing, Risk-aversion, CVaR*

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BATCH QUANTITIES WHEN FORECASTS ARE IMPROVING

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This paper considers the choice of initial batch quantities when demand forecasts are improving. We assume that the standard deviation of the demand per period is decreasing exponentially and approaching a long run value. A discrete time stochastic single-level inventory model is considered. There are traditional holding and backorder costs as well as an ordering cost. The ordering periods must be determined in advance, and we wish to determine a suitable schedule.

Introduction: Lot sizing models dealing with stationary demand nearly always consider lot sizes that are appropriate in the long run when the system has reached steady-state. Still there are several reasons to use different lot sizes in an initial transient phase. One such situation is when demand cannot be satisfied until a batch is delivered, there is no initial stock, and the production rate is finite. It is then normally optimal to use smaller initial batch quantities so that demand can be satisfied earlier. Examples of models dealing with this aspect is Axsäter (1988), Ding and Grubbström (1991), and Grubbström and Ding (1993). Another reason to use different initial batch quantities may be learning and forgetting effects, which affect the production rate. See e.g., Elmaghraby (1990), and Klastorin and Moinzadeh (1989).

This paper deals with a further aspect of initial lot sizing. We assume that the forecast error is large in the beginning, but that the forecasts are rapidly improving. It is assumed that the standard deviation of the demand per period is decreasing exponentially. A small initial order will quickly improve the forecast accuracy when determining the next order, and it turns out that we also in this situation, in general, should use a smaller batch in the beginning.

The outline of the paper is as follows. In Section 2 we give a problem formulation. In Section 3 we demonstrate how to obtain the optimal solution by a dynamic programming approach. Section 4 provides some numerical results and finally we give some concluding remarks in Section 5.

Keywords: *inventory management, lot sizing, transient, stochastic*

ON THE EXACT AND ESTIMATED CALCULATION OF THE MEAN STOCK LEVEL IN PERIODIC REVIEW SYSTEMS

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One of the most usual indicators to measure the performance of a stock policy is the mean physical stock whenever a target service level has been fulfilled. However its exact calculation requires a high computational effort and therefore several approximations are used in practice. In a previous work, Van der Heijden, M. C. and de Kok, T. (1998) propose an exact calculation for the mean physical stock that applies with continuos demand pattern and compare it with standard approximations. In this paper it is proposed an exact method to compute the mean physical stock able to apply to any stationary, discrete and *i.i.d.* demand pattern. This new method is based on computing the probability of every physical stock level at every point of the cycle. For that, it is adopted the same reasoning used by Cardós, M. et al. (2006) in which the probability of every stock level is obtained using the probability transition matrix between the inventory levels from one time-point to the following one. Additionally an experiment is carried out to measure the efficiency of this new method when compared with the classical Hadley-Within approximation and the linear approximation including the Simpson´s and the 3/8 rule.

Finally the objective of this work is to establish under which conditions, in terms of both demand pattern and target cycle service level, it is required the application of the exact method and when approximations are accurate enough.

Keywords: *physical stock, exact method, discrete demand pattern*

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OPTIMAL ECONOMIC ORDERING POLICY WITH DETERIORATING ITEMS UNDER DIFFERENT SUPPLIER TRADE CREDITS FOR FINITE HORIZON CASE

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This paper develops and solves a general finite horizon trade credit economic ordering policy for an inventory model with deteriorating items under inflation and time value of money when shortages are not allowed. The time horizon is divided into different cycles each of which has its own demand rate and its own trade credit period offered from the supplier to his retailer so that the retailer should pay his supplier before or after the end of the permissible trade credit of that cycle. Up to the end of the trade credit of a cycle, the retailer is free of charge, but he is charged on an interest for those items not being sold before this end. The retailer can also earn the interest of the money from the generated sales revenue in any cycle by depositing such revenue into an interest bearing account. The objective of the retailer is then to minimize his net total relevant costs. A closed form of this net total cost is derived and the resulting model is solved. Then rigorous mathematical methods are used to show that, under some seemingly possible conditions, there exist a unique vector of the relevant decision variables that solve the underlying inventory system. A numerical example which shows the applicability of the theoretical results is given.

Keywords: *Inventory Control, Credit Policies, Order Quantities, Global optimality, Deterioration, Inflation, Time Value of Money*

A DISTRIBUTION-FREE NEWSVENDOR MODEL WITH BALKING AND LOST SALES PENALTY

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This paper is an extension of the classical single period inventory (newsvendor) problem with possible customer balking and a linear lost sales penalty. The traditional newsvendor model is useful for determining ordering policies for relatively short shelf-life products, e.g. baked goods, perishable agricultural produce, newspapers, etc., in order to maximize the expected profit for a single period under a stochastic demand environment. This is achieved by finding the optimal tradeoff between the risk of over-stocking (incurring disposal cost) and the risk of under-stocking (losing the opportunity of earning a profit) an item. This model has found numerous practical managerial applications in real world inventory control situations, including the sporting goods, fashion and apparel industries, and has received a great deal of research attention. In recent years, a variety of extensions and embellishments to the classical single period model have been proposed in the extant literature. These extensions include conditions of random yields, the possibility of additional order opportunities, the presence of fixed costs and resource constraints, etc. In practice, it is sometimes difficult to determine the exact distribution of random customer demand during the sales period in question, primarily due to a lack of adequate data. For coping with such circumstances, some researchers have analyzed distribution-free newsvendor models, where the distribution of demand is unknown, but its mean and the variance are determined or can be readily estimated. Generally speaking, solution methodologies that seek to maximize (or minimize) total profit (or total cost) resulting from the worst possible case of demand distribution have been employed for solving the distribution-free model. We adopt a similar approach in this paper. More recently, the phenomenon of customer balking in the context of the newsvendor problem has been considered. Under such a scenario, the probability of a customer making a purchase of the product in question declines from 1 to L ($0 \leq L < 1$) if its available inventory falls below a threshold level K. Such customer balking is not uncommon in the case of perishable items, where the likelihood of a customer purchase declines if there are just one or a few items (albeit free of defects) are available on the shelf. In this paper, we incorporate an additional linear penalty for lost sales, as a consequence of under-stocking the item. This issue has been largely bypassed in existing distribution-free single period models with balking. Although the cost of lost sales (due to loss of customer goodwill, long term loss of market share, etc.) is often difficult to estimate in practice, we contend that such a cost, more often than not, is important and significant enough to be taken into account. Thus, the major aim of this paper is to outline a procedure for deriving the optimal ordering policy for the distribution-free newsvendor model with balking and a linear lost sales penalty. Finally, we report our computational experience and present some concluding remarks after solving a set of 100 randomly generated problems.

***Keywords**: Newsvendor model, distribution-free, inventory, single period.*

AN INTEGRATED PRODUCTION-DISTRIBUTION MODEL FOR A DETERIORATING ITEM IN A TWO-ECHELON SUPPLY CHAIN

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In the real world, it is not uncommon for continuously stocked inventory items to decay or deteriorate over time (e.g. dairy products, blood, agricultural produce, pharmaceuticals, etc.). Thus, it is important to understand the deterioration behavior of such products, towards the formulation of appropriate and effective inventory control policies that explicitly take into account their respective decay phenomena, especially in a supply chain context. The existing literature on deterioration inventory models has had a rich history over the past four and a half decades. In recent years, a number of researchers have examined the effects of adopting a variety of probability distributions for modeling decay processes. Nevertheless, in a majority of the studies in this area, the decay rate is assumed to be a constant fraction of the available inventory level. Also, most existing decaying item inventory models are of the EOQ type and consider the different stages of multi-echelon supply chains independently, rather than in an integrated manner. In this paper, we develop an integrated production-distribution model for a deteriorating inventory item in a two-echelon supply chain, consisting of a single buyer (or retailer) and a single supplier (or manufacturer) under deterministic conditions. For achieving coordination of the production and distribution decisions, we assume that the supplier employs a production batch size which is an integer multiple of the delivery lot size, both of which are fixed, once they have been appropriately determined. Such a policy is common in JIT environments (often described as lean production systems). Of the existing inventory models concerning decaying items, relatively few have been developed explicitly for such operating environments. Furthermore, a bulk of the solution approaches employed in deterioration inventory models are calculus based. Such approaches may not always be effective in the case of multi-echelon supply chains, where at specific delivery (or receipt) points the inventory levels of the supplier, as well as the buyer change suddenly, resulting in inflexions in their respective inventory levels and costs. This renders the implementation of classical optimization techniques cumbersome. With the commonly adopted assumption that the item's deterioration rate is constant and small enough, such that its square and higher powers can be neglected, we develop the respective cost functions of the supplier, the buyer and the entire supply chain. We then propose an algebraic method for deriving optimal policies from the perspectives of each member of the supply chain, as well as the entire supply chain. Our methodology is illustrated via a numerical example and, finally, an extensive sensitivity analysis leads to some insightful concluding observations.

***Keywords**: Inventory, supply chain, deterioration, integrated model, JIT*

MODELLING THE LEVEL OF REPAIR ANALYSIS PROBLEM AS A MINIMUM COST FLOW MODEL

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Generally, capital goods, such as military naval equipment, mri-scanners, or trains, are repaired by replacement of subsystems by spares. The defective subsystem can either be discarded or repaired. If the subsystem (component) is repaired, this is achieved by replacement of the subcomponent that failed by a spare. The subcomponent should in turn be repaired or discarded itself. A product can thus be seen as a multi-indenture system such as shown in Figure 1.

A military organisation or a manufacturer (OEM) that sold a service contract may be responsible for achieving a certain operational availability of the products. The installed base can geographically be very dispersed, so that it is necessary to have a repair network with different locations where spares are located and/or repairs can be performed. Such a repair network can consist of different echelons; see Figure 2 for an example.

Given a product design and a repair network, a level of repair analysis (LORA) shows for each component in the product (1) whether it should be discarded or repaired upon failure and (2) where to do that. The objective of the LORA is to minimize the total (variable and fixed) costs. Optimal spare part stock levels, needed to guarantee a certain availability of the products, are usually determined after the LORA has been performed.

In a previous paper (Basten et al., 2007), we proposed a mixed integer programming model that solves the LORA problem, based on cases that we have seen at Thales Nederland, a manufacturer of naval sensors and naval command and control systems. In the current paper we show how the LORA problem can be modelled as a minimum cost flow problem with side constraints. We use this new formulation because it enables us to extend the model to cover, amongst other things:

- A certain probability of succesful repair p, instead of a 100% probability of successful repair.
- Different types of failures per component. For example, in 60% of the cases a tester is needed, in 40% of the cases the tester is not needed. The different repairs might be performed at different echelons.
- A step function in the fixed costs: Basten et al. (2007) used a binary variable that indicates whether or not certain fixed costs need to be accounted. However, if fixed costs are accounted to buy a tester, this tester cannot be used to test an infinite amount of components. A second and even a third tester might be needed.

We performed tests on instances with a size realistic in practice. We based the tests on cases at Thales Nederland and we can solve them in a reasonable amount of time.

***Keywords**: Level of repair analysis, Integer programming, Minimum cost flows*

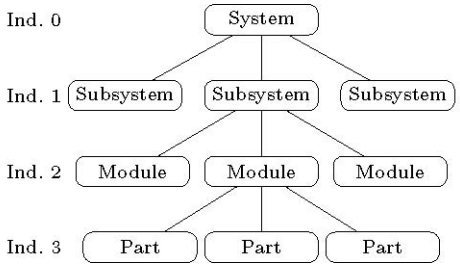

Figure 1 – A multi-indenture system

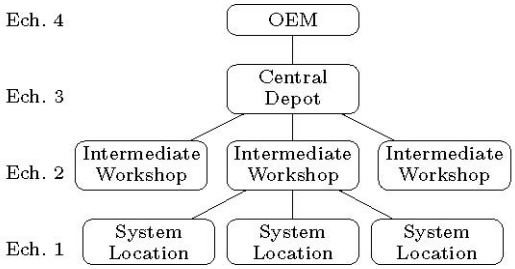

Figure 2 – A multi-echelon repair network

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INVENTORY CONTROL AND QUASI-VARIATIONAL INEQUALITIES

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This paper presents a Quasi-Variational (QVI) formulation, for determining the optimal replenishment schedule which minimizes the total expected cost over an infinite planning horizon, for a number of inventory control models. These models range from the classical discrete time stationary model of Scarf to models with demand driven by diffusion processes and jumps processes. Further, these models cover models with deteriorating items and stock dependent demand items. Optimality of $(s; S)$ policies is established using QVI techniques. The tool for showing optimality reveals a interesting property of the optimal expected inventory cost function which should make the computations of the optimal $(s; S)$ an exercise in numerical analysis.

EQUILIBRIUM PROBABILITIES OF LOST SALES INVENTORY SYSTEMS

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Nowadays, the retail environment becomes more competitive and customers tend to be less committed to one brand. Consequently, if a demand occurs and the product is not available the customer buys another product or goes to another store. Either way, the original demand of the customer can be regarded as lost instead of being backordered. Orders and deliveries are usually performed on a regular basis in practice. Therefore, we consider a single-item, periodic review inventory system with lost sales. In this paper, we develop a tool that can be used to find optimal order sizes for any replenishment policy, any demand distribution and any objective function under the mentioned conditions.

Lost sales models have received considerably less attention in the inventory literature compared to backorder models, due to the more complex nature of the problem (see Hadley and Whithin[1963]). However, since the lost sales characteristic is often seen in competitive markets, this is an interesting and worthwhile subject to investigate. In the literature, almost all periodic review, lost sales models with positive lead times restrict to situations where at most one or two orders are outstanding by imposing restrictions on parameter values. Another assumption found in most literature, is that lead times are usually assumed to be integer multiples of the review period. Fractional lead times models restrict to situations with lead times less than the time between two review moments (Kapalka et al.[1999],Janakiraman and Muckstadt[2004],Chiang[2006,2007]). Consequently, at most one order is outstanding at any time. In this paper we do not impose any restrictions on the parameter values or on the lead time.

All models in the literature imply a fixed objective function and a fixed replenishment policy that need to be altered if other ones are desired (e.g.,Huh et al.[2006],Zipkin[2007]). It would be more interesting to find a single expression for the equilibrium (or limiting) probabilities of the inventory system at the review moments in order to address all kinds of performance measures of the inventory system. The objective of this paper is therefore to develop a general and efficient approach to determine these equilibrium probabilities which can be used for any demand distribution and any replenishment policy.

A Markov chain is used to model the inventory system and to determine the equilibrium probabilities. We also present an alternative representation based on dynamic programming. Finding the equilibrium probabilities is however very time consuming, especially when they are used to find optimal parameter values. Therefore, we also develop an efficient approximation procedure and test the performance for different scenarios (different replenishment policies, different demand distributions). The numerical results show that the results of the approximation procedure are close to the actual equilibrium probabilities. We also compute different performance measures (total costs, fill rate) based on the approximated equilibrium probabilities. These results are even closer to the actual values. Based on these results we conclude that we have developed a general procedure to analyze

periodic review, lost sales inventory systems. This procedure can be used to find near-optimal parameter values.

Keywords: *inventory, lost sales, periodic review*

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LOCATION OF ACTIVITY CELLS IN DISTRIBUTION AND REVERSE LOGISTICS

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In this paper we study some aspects of activity cells location in extended MRP model, previously developed by Grubbström and his Linköping School which has been extended by distribution and reverse logistics component in a compact form, presented by Grubbström, Bogataj and Bogataj (2007). Our aim is to demonstrate the possibilities how to present location aspects in the supply chain model obtained from combining input-output analysis and Laplace transforms in four sub-systems, namely manufacturing, distribution, consumption, and reverse logistics, and to show how the transportation costs and lead time influenced by location of all these activities influences net Present value (NPV). Here we will concentrate our analysis on the location problems especially in two sub-systems of distribution and reverse logistics, introduced always if we want to close the loop of flows in a global supply chains.

Introduction: Optimal decisions (i) where to produce, (ii) where to locate distribution centres and (iii) where to organise reverse activities in integrated supply chain can be successfully discussed and evaluated in transformed environment, where lead times and other time delays can be considered in linear form. The integrated approach is especially needed when we consider reverse logistics as an extended producer responsibility. This responsibility is internalised through taxes for disposal, which is different in different regions, therefore, depends on location of activity cells. The responsibility of producers for their products is extended to the post-consumer stage. A company or partners in a supply chains must be concerned not only with making the product and how it functions, but also with what will become of the product at the end of its useful life. In the case of consumer goods, this principle shifts responsibility for recycling and waste disposal from local government to mainly private actors in a supply chain. It means internalising the costs of waste management into product prices. Under such a scheme, citizens pay for waste management as consumers, when purchasing products, rather than as taxpayers, through local taxes. The price of disposal in our model mainly includes that costs of disposal which are prescribed by local or governmental taxes collected on the way that costs of waste are internalised (mainly so that consumer are previously allowed to return the waste to producer it means to the supply chain to which it belong. The disposal flow depends on percentage of the return rate α, location of activity and transportation costs for transportation between two cells in a global supply chain. It depends also on technology, labour and quality of the product at the end of its useful life, as well as on local environmental restrictions for activity cells.

The main methodology: The site and capacity selection, as for instance the problems where it is best to locate a facility and what capacity is needed to achieve the most rapid response, are discussed more easily in transformed environment (Aseltine, 1958), using MRP (Orlicky, 1975) and I-O analysis (Leontief, 1951) in Laplace transformed space, as previously presented by Grubbström (1996,1998,2007) and in many other papers of his Linköping

research group. The extension of the production network has been done to distribution part (see Bogataj, M., Bogataj, L., 2003) and later by Grubbström, Bogataj and Bogataj (2007) in close loop of product life cycle, including also reverse logistics. The labour cost and other costs of activities appear in every activity cell. These costs depend on location of activity cells. Together with transportation costs and costs of delay, which all depend on distances between two activity cells, (it means that it depends also on location of that cells), they influences NPV as the criterion function of all activities in a chain. Reverse logistics activities intend to reduce the amount of materials going to landfills but the optimal percentage of disposal should be decided when optimising the net present value of all activities in the supply chain, having in mind environmental policies, technology available and cost of labour at different locations. Its underlying theory is that if producers must pay for waste, they will have an incentive to make products that are less wasteful. The approach we suggest provides the missing link between product design and recycling: a link that is the key for making recycling efficient and economic. The movement toward designing for disassembly, developing reverse logistics systems, and remanufacturing, are strategies industry in supply chains has to use in response to the new incentives posed by new European and American incentives. The recycling sub-system may be viewed as a production function having one input (used components from different locations of consumption, where different prices of product can be achieved). All this activities are integrated in matrix presentation and numerical analysis of a chain and the model can be elaborated as presented in Grubbström, Bogataj and Bogataj (2007). This production function has two outputs (reconditioned components and irreparable components to be disposed of).

The basic results: The basic results are modified EOQ formulas as the components of production vector, where set up costs are extended with transportation costs, influenced by distance between activity cells. The lead time also include the influence of distances between two activity cells, while among all costs, appeared in NPV formula, cost of labour, which differs from location to location also influence NPV. Sensitivity results of environmental policy at a region influencing NPV can be easily obtained using this approach.

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OPTIMISATION OF DISTRIBUTION AND REVERSE LOGISTICS IN TIME DOMAIN FOR SUPPLY CHAIN OF PERISHABLE GOODS

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In this paper we extend MRP theory to distribution and reverse logistics sub – systems, when the items in the supply chain could be perishable and analysis is given totally in time domain.

We intend to show that all retarded sub-systems in global supply chain could be accurately described using input and output matrices collected together in corresponding matrices for the system as a whole. As suggested in Grubbström's theory of MRP systems, the model is formalised, but it is suggested to solve the system in time domain. The theory of optimal control of hereditary systems is applied to solve the stated problem in real time. The lead times in the system of perishable goods are getting a particular attention.

In the paper we have developed the mathematical derivations and results for perturbed adjoint operator for linear hereditary systems having linear – quadratic form typical for global supply chains considered by the theory of Orlicky, Leontief and Grubbström and later extended by Bogataj M. and Bogataj L. and generalised in the paper of Grubbström, Bogataj and Bogataj (to appear in 2008).

The flows in a global supply chain are often perturbed. The perturbations can be presented in perturbed adjoint operator for linear hereditary differential systems considering finite magnitude perturbations of systems matrices being characterised here. The system is described by linear differential – delay equation with the delays in the state of the system, influenced by environment and conservation procedures, and in the control, influenced by production, distribution and reverse logistics perturbations. Net present value is given as criterion function. The impact of perturbations on the state of the system and the impact on the control are studied separately.

In the paper we shall show how to derive the perturbed adjoint operator for the infinitesimal generator of a strongly continuous semi-group of linear operators for linear hereditary differential systems with delay in the state, presented lead time and perturbations influenced by transportation problems. The importance of the results for real world supply chain problems lies in the fact that considered perturbations in the delay in the control can be of finite magnitude, which is the case, when MRP is extended in total supply chain having globally distributed activity cells.

The application of mathematical results obtained in functional analysis, well described in the papers of Nakagiri, S., Structural properties of functional differential equations in Banach spaces, Osaka J. Math, 25 (1988), considered in extended MRP systems, described in Grubbström, Bogataj and Bogataj paper (2008), is going to give new insight in perturbed global supply chains.

Keywords: *Hereditary differential systems, Supply chain, Perturbations, Input – output analysis*

EXACT AND APPROXIMATED CALCULATION OF THE CYCLE SERVICE LEVEL IN CONTINUOUS REVIEW INVENTORY POLICIES

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This paper is part of a wider research project devoted to identify the most simple and effective stock policy to properly manage any particular demand pattern based on the characteristics of the demand itself. In order to attain this objective, it is necessary to be able to compute the exact cycle service level (CSL) to assure the fulfilment of a given target CSL.

Previous papers (Cardós et al., 2006; Cardós and Babiloni; 2008) focused on the periodic review policy with a known, discrete, stationary and *i.i.d.* demand pattern. It has been proposed a new definition of the cycle service level to be useful for any demand pattern and it has been proposed a method to compute the exact CSL. This method involves such a computational effort that it became necessary to asses approximations to provide easier and accurate estimations.

The main aim of this paper is to continue the approach outlined above applied to the continuous review policy instead of to the periodic review policy. Therefore, the specific objectives of this paper will be: (a) to check if the new proposed definition of CSL applies to continuous review policies; (b) to develop an exact calculation method of the CSL for a continuous review policy given a known, discrete, stationary and *i.i.d.* demand pattern; and (c) to propose and evaluate the approximations for an affordable computational effort.

Keywords: *continuous review policy, cycle service level, exact method, discrete demand pattern*

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AN ONLINE SEARCH FOR AN OPTIMIZATION OF CONTAINER STACKING POLICY IN A CONTAINER TERMINAL

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In a container terminal, containers transported to the terminal are temporarily stored in the area called stacking yard until they are loaded onto container vessels or claimed by container trucks for road transport. Deciding a desirable stacking position for each incoming container is one of the most important operational problems in a container terminal. Inappropriate stacking of containers can greatly deteriorate the productivity of the container terminal because the retrieval operation of those containers at the time of loading becomes inefficient. Sometimes the containers may have to be temporarily relocated, or rehandled, in order to retrieve a target container stacked beneath. Some other times the stacking cranes may have to travel a long distance to retrieve the containers that have to be loaded consecutively. To be able to determine optimal stacking positions, we must take into account a variety of factors including the possibility of interference between stacking cranes, the future workload distribution of stacking cranes, the probability of the occurrence of rehandling at the time of container retrieval, etc. By making a weighted sum of the evaluation values of these factors, we can come up with a numeric value that represents the goodness of a stacking position. In this case, the vector of those weights constitutes a stacking policy.

Notice that how good a stacking policy is can be determined only after the containers stacked by the policy are all retrieved out of the yard. Since the dwell time of the containers typically ranges from a day to a couple of weeks, it takes at least two weeks of operational simulation to evaluate a stacking policy. Therefore, optimizing the weight vector using offline search demands a considerable amount of computation time. In this paper, we propose an online search algorithm which dynamically adjusts the weights and evaluates them. The algorithm repeats creating a slight variation of the best-so-far weight vector and applying it as a candidate policy at a relatively short predetermined interval. The evaluation value of a candidate policy can be obtained after a predetermined evaluation period which is much longer than the application interval, and a new candidate policy is created from the newly selected best-so-far policy. Note that a series of candidate policies are applied consecutively and thus the evaluation periods of these policies overlap each other. The proposed algorithm requires much less time to optimize the stacking policy compared to the offline search method. In addition, due to the dynamic nature of our algorithm, it can rapidly adapt the stacking policy to the change of the operational environment. The simulation experiment shows that the proposed algorithm is effective in reducing the delay time of quay cranes which are the most important resources in container terminals.

Keywords: *Container terminal, stacking yard, container stacking policy, online search*

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A STOCHASTIC DYNAMIC MODEL FOR A MULTI LOCATION INVENTORY PROBLEM

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We consider a One-Warehouse Multi-Retailer (OWMR) system where retailers are not identical. Replenishment times are fixed for each stocking point, and retailers face discrete stochastic demand. Excess demand is fully backordered with linear penalty costs. The objective is to minimize the expected total cost of the system over a finite horizon of periods.

The optimization of such a system requires the analysis of a multi-dimensional dynamic program because of the sequential allocation problem. We first develop a model which represents the stochastic cost structure of a two-echelon distribution network. Then we present the dynamic programming model for optimal inventory management of an OWNR system under periodic review. Considering the curse of dimensionality, we develop a computationally efficient dynamic programming based heuristic which is based on the restriction of the policy space according to optimal lot sizes of the retailers. We named this algorithm as Order-to-Allocate (OA), since it tries to find out best order quantities for the distributor, according to optimal allocation for the retailers considering that the next order and allocation decision will be done due to retailers optima.

The algorithm works as follows: We start with optimization of retailers' lot sizing problem for each feasible value of order quantities in distributor's lead time. Then, we formulate the allocation problem on distributor's side by using expected optimal order quantities of all retailers and corresponding expected optimal lot sizing policies and total costs. Finally, we obtain optimality equations of overall system by adding distributor's lot sizing problem which depends on the optimal allocation quantities obtained in the second level.

The proposed approximation algorithm has the form of rolling horizon algorithm that the overall problem is solved for the periods of distributor lead time based on the starting state of the system. Hence, even though it resembles a myopic algorithm, it is based on the consideration of retailers and distributor's long term costs. Even though the distributor seems to make the allocation decision only once in the beginning of the planning horizon, this allocation decision will be repeated in the beginning of the next periods which will give the distributor the chance of reallocating the system wide costs according to retailers and overall system's inventory levels. This creates a smoothing effect on the first period order policy according to long term inventory costs.

We investigate the performance of OA based replenishment policies via numerical experiments to identify the settings in which the approximation gives significant deviation from optimal value. Results from the numerical examples show that in general, OA performs better when the difference between the retailers' independent optimal policies are similar to overall system's optimal policy.

SAFETY STOCK PLANNING WITH THE HUNGARIAN INVENTORY CONTROL MODEL IN A REVERSE LOGISTICS ENVIRONMENT

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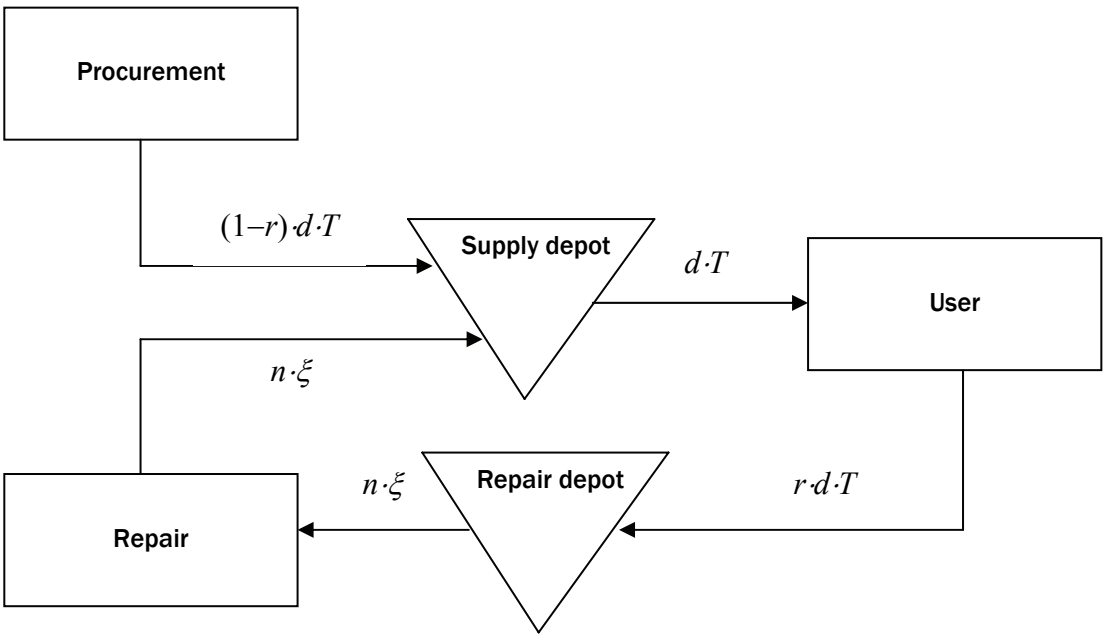
The "Hungarian inventory control model" and its applications are investigated extensively in the literature. (Kelle, P. (1985): Safety stock planning in a multi-stage production-inventory system, Engineering and Production Economics 9, 231-237, Prékopa, A. (2006): On the Hungarian inventory control model, European Journal of Operational Research 171, 894-914, Noyan, N., Prékopa, A. (2006): A variant of the Hungarian inventory control model, International Journal of Production Economics 103, 784-797) The present work examines a reverse logistics model with deterministic purchasing and stochastic reuse process. The aim of the paper is to determine the safety stocks for the new and used products in case of known and linear demand process. The model is similar to that of Kelle's model (1985).

The model investigates the next problem. First we show the material flow in the model:



Parameters of the model:

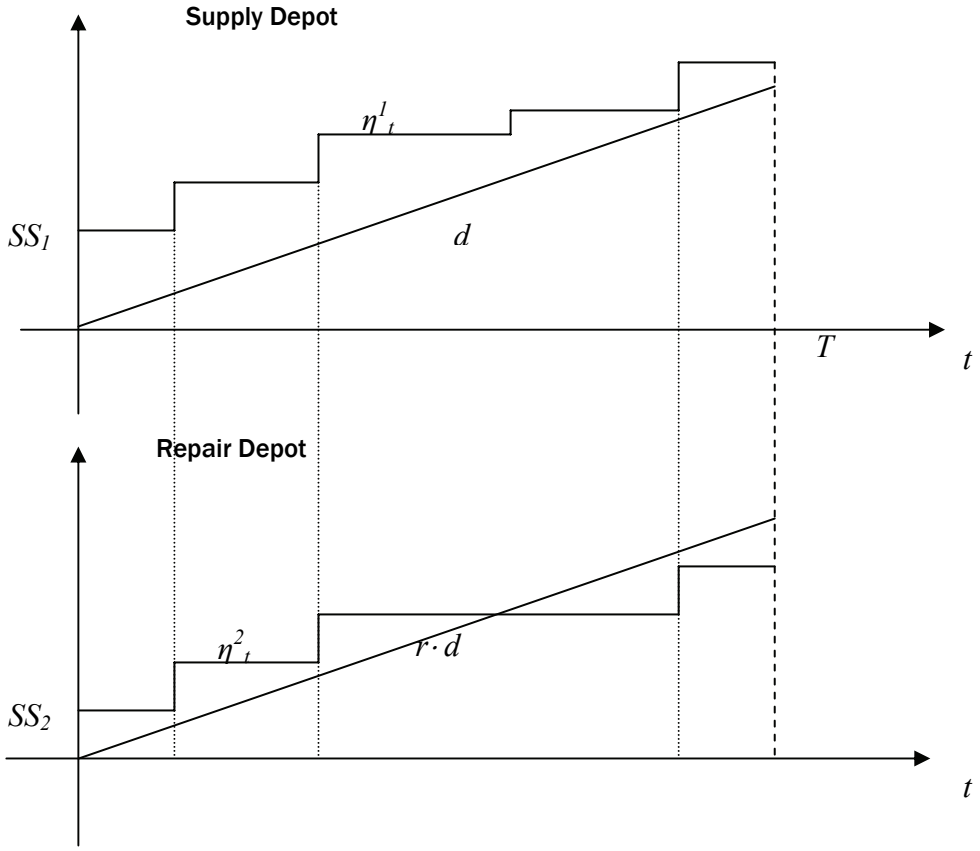
- demand $d\cdot T$,
- number of supplies n,
- $n\cdot\xi = d\cdot T$,
- known service level in supply depot $1-\varepsilon_1$,
- known service level in repair depot $1-\varepsilon_2$,
- safety stock in supply depot SS_1,

- safety stock in repair depot SS_2,
- purchasing price of the new product p_1,
- purchasing price of the used product p_2.

Safety stock in supply depot: $$P\left(SS_1 + \eta_t^1 + (1-r)\cdot d \cdot T \geq d \cdot T\right) = 1 - \varepsilon_1 . \quad (1)$$

Safety stock in reapir depot: $$P\left(SS_2 + \eta_t^2 \geq r \cdot d \cdot T\right) = 1 - \varepsilon_2 . \quad (2)$$

The stocks in the depots are depicted in the following figures:



The aim of the paper is now to solve the following stochastic programming problem:

$$F\left(SS_1, SS_2\right) = p_1 \cdot SS_1 + p_2 \cdot SS_2 \rightarrow \min$$

such that (1) and (2).

Keywords: *Reverse logistics, Hungarian inventory control, safety stocks*

SOLUTION OF WAGNER-WHITIN TYPE REVERSE LOGISTICS MODELS WITH GENETIC ALGORITHM

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The aim of the paper is to investigate the reverse logistics initiated by Richter and Sombrutzki (2000). The properties of the model were analyzed extensively in the literature. The model has the following form:

$$\begin{aligned} I_t &= I_{t-1} + Q_t^P + Q_t^R - D_t \\ i_t &= i_{t-1} - Q_t^R + R_t \end{aligned}, \qquad (t = 1,2,\ldots,T)$$

$$\begin{aligned} &I_t \geq 0, \quad i_t \geq 0, \\ &Q_t^P \geq 0, \quad Q_t^R \geq 0. \end{aligned}, \qquad (t = 1,2,\ldots,T)$$

where $I_0 = i_0 = 0$. The first equality is the balance connection in tth period for new products, i.e. the inventory level at the end of period t is equal to the sum of initial inventory level, purchasing and repair reduced with demand. The second equation includes the returned items and the items taken in reuse process. The last inequalities are the nonnegativity conditions of variables.

The cost function is

$$\sum_{t=1}^{T} \left(A_P \cdot sign\, Q_t^P + h_1 \cdot I_t + A_R \cdot sign\, Q_t^R + h_2 \cdot i_t \right) \rightarrow \min .$$

Parameters of the model:

- D_t demand for new products in period t, nonnegative,
- R_t returned used items in period t, nonnegative,
- I_0 initial inventory level of new products,
- i_0 initial inventory level of returned items,
- A_P fixed procurement cost, per order,
- A_R fixed repair batch induction cost, per batch,
- h_1 holding cost of new products,
- h_2 holding cost of used items,
- T length of planning horizon.

Variables of the model:

- I_t inventory level of new product in period t, nonnegative,
- i_t inventory level of used items in period t, nonnegative,
- Q_P procurement quantity, nonnegative,
- Q_R repair batch size nonnegative.

Richter and Sombrutzki (2000) have proven some properties of the model:

It holds in optimal solution:

i) $Q_t^P \cdot Q_t^R = 0$, $(t = 1,2,...,T)$

ii) $I_{t-1} \cdot (Q_t^P + Q_t^R) = 0$, $(t = 1,2,...,T)$.

The solution of such kind models is very complicated and the problem is NP-hard. In this paper we offer a meta-heuristics to solve the problem, namely genetic algorithm. We show the efficiency of the proposed method and examine the dependence of the solution on parameter variation.

Keywords: *Reverse logistics, genetic algorithm, Wagner-Whitin type model, lotsizing*

COMPARISON OF (R, S) AND (s, S) POLICIES UNDER NON-STATIONARY DEMAND

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We consider a periodic review single-item inventory system facing non-stationary stochastic demand of the customers in a finite horizon. There is a demand forecast for each period in the planning horizon (point forecast), and the forecast errors are assumed to be distributed normally. A fixed cost of ordering, which is independent of the quantity ordered, is charged every time an order is placed with a supplier with ample stock. Any unfulfilled demand is backlogged, and a penalty cost per unit of backlog per period is charged. Moreover, for any unit of inventory kept at the end of a period, a holding cost is incurred.

The class of (s, S) policy is known to be optimal for the system under study. However, from both computational and operational (practical) point of view, optimizing and implementing (s, S) policies can be difficult. Although suboptimal, the class of (R, S) policies is practically an attractive alternative. In an (R, S) policy, the timing of future orders with the associated base stock levels are fixed, a desirable property that decreases the nervousness in the system and provides valuable information to the supplier. However, calculating the optimal parameters of an (R, S) policy under non-stationary stochastic demand is a challenging task. Hence, the studies in the literature so far have focussed on computationally efficient approximations, see Silver (1978), Tan and Bookbinder (1988), and Tarim and Kingsman (2004, 2006).

Even though each study provides numerical evidence for the performance of the approach, there is no study that compares these approximations against the true optimal (R, S) policy. This is a numerical study that tries to fill this gap in the literature. We not only compare the performance of the approximations against the optimal (R, S) policy, but also against the optimal (s, S) policy, which is the true optimal policy from a pure cost standpoint for the inventory system under consideration. The results from an extensive test bed of instances provide valuable insights on (i) the error in the approximate approaches, (ii) the error introduced by selecting a suboptimal class of policy.

Keywords: *Non-stationary stochastic demand; (R,S) policy; (s,S) policy; Approximations*

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AN INVENTORY PLANNING PORTFOLIO FOR PRODUCTS WITH UNCERTAIN LIFE-CYCLE

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Despite the interest towards the Just-In-Time production paradigm in the last decades, the "zero inventory" concept has hardly ever been realised in practice due to the fluctuating market demand and the challenges caused by increasing customer expectations (Chikán, 2007). Inventories are still essential to hedge against uncertainties; however, because of today's shortening product life-cycles, huge obsolete stocks may accumulate resulting in serious waste of both financial and environmental resources.

In this paper we extend two classical mathematical models with consideration to the changed economic situation: specifically, the uncapacitated single item lot-sizing (USILP) and the one-period newsvendor models. We introduce the stochastic length of the product's life into the former model and include the expected cost of obsolete inventory into the objective function. The resulting stochastic program can then be solved efficiently with a modified Wagner-Whitin algorithm. An important assumption of this model is that the demand should be satisfied without backlogs, thus as part of the inventory, safety stock has to be included in order to avoid short-term stock-outs caused by market uncertainty. However, the stock level should be kept at a minimal level. On the other hand, the newsvendor model is extended to the situation when the complete demand should be satisfied even with a costly additional setup. While the first model is applicable for planning inventory levels on a multi-period, rolling horizon, the modified newsvendor model can capture the end-of-life situation of the product. We also describe how these two complementary models can be combined into a unified approach and practically applied in order to cope with the conflicting issues of obsolete inventory and maximal service level.

The motivation of this work comes from a large-scale national industrial-academic RTD project aimed at realising real-time, cooperative enterprises. The industrial partners form a focal supply network with a central end-product manufacturer and several internal and external (including customised packaging material) suppliers around. We demonstrate therefore through extensive numerical examples—using also industrial historical data—how the proposed algorithms perform in practical situations. Other simulations made with large amount of random data can give more insights into the general properties of the described inventory planning methods. Finally, we mention that the optimal inventory levels proposed by the above methods can be achieved also in a decentralised, two-echelon supply chain setting with asymmetric information applying specific incentive-compatible contracts that facilitate cooperation of the partners (Egri and Váncza, 2007) and (Váncza et al., 2008).

Keywords: *Inventory planning, newsvendor, Wagner-Whitin, obsolete inventory*

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THE INFLUENCE OF COSTS' DEVIATION ON THE PLAYERS' PROBABILITIES IN A NON-COOPERATIVE GAME

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For industrial companies it is important to optimize the purchase order quantities. Lot sizes have an influence on storage, procurement, service level and readiness for production. An incorrect lot size planning results in higher costs and in profit setbacks, which the top management tries to avoid. Therefore the management expects the material manager to realise an optimal lot size. Normally this is audited by a controller, who reports the situation to the top management.

The interaction between the material manager and the controller can be described by a modified Inspection Game (Fandel/Trockel 2008). In this game on the one hand the material manager disposes of two strategies: Calculating on the basis of a methodically established decision or calculating "on instinct". On the other hand the controller has the two strategies: Auditing the lot size planning on a high or a low level. The controller's audit report will be checked by the management with a specific probability. Unfavourable decisions of the material manager, which are detected by the controller, implicate a penalty – e.g. a loss of reputation. As well as a low auditing level of the controller will reduce his payoff if the top management notices bad work done by the two players.

It was shown in Fandel/Trockel in 2008, how a Nash equilibrium of a material manager–controller–game in mixed strategies depends on fixed payoffs and the probability of detecting bad decisions of the material manager and the controller. In this article it will be analysed, how probabilities, which are the basis for the mixed strategies in the equilibrium, will be changed, if the amount of the penalties of the two players depends on the costs' deviation caused by the bad material manager's lot size planning. Thereby it is shown, that the combination of the strategies (decision "on instinct"; low auditing level) occurs with lower probabilities than the Nash equilibrium, in which the controller's and the material manager's penalties are independent of the costs' deviation.

Penalties, which depend on the deviation, and an accurate audit of the controller's report by the top management prove to be the best instruments to avoid a malpractice of the material manager and a bad controller's audit, both leading to high costs.

Keywords: *stockkeeping, auditing, non-cooperative game theory*

Reference:
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CONSEQUENCES OF TEMPORAL BUYBACKS PRACTICED IN THE BOOK INDUSTRY

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Book publishers in many countries allow booksellers to return all unsold copies of a title for a full refund, albeit the costs of return (shipping, handling) are assumed by the bookseller. To qualify, return of books needs to take place within a certain time from the delivery to the store. We construct a model for a given title with uncertain retail demand, in which, at some point in time, the retailer can return unsold copies to the publisher, or order more copies. Given a time window for returns, the selling horizon is divided into two periods, with the possibility of returns or replenishment at the end of the first period. The retail price in the second period may differ from that of the first. All these variables depend on the relative lengths of the two periods, which constitute a key strategic variable in our model. We characterize the optimal replenishment policy and conduct numerical experiments to investigate the impact of different market and operating factors on the optimal length of the return time window for both decentralized and centralized chains. In addition, we briefly consider how to coordinate the supply chain, which requires period-dependent revenue shares, in addition to wholesale prices and midlife returns. Some possible extensions of our model are also discussed.

Keywords: *Temporal Newsvendor, Buybacks, Publishing Industry.*

*Part of this work was done when this author was visiting McGill University

JOINT PRICING AND ORDERING DECISIONS FOR PERISHABLE INVENTORY

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Since the early fifties the interface between operations management and marketing has experienced increased emphasis and a joint optimization of the supply (procurement) and the demand side (price, promotion) has been recognized as a fruitful research domain to improve a firm's bottom line. However, most of the commonly used models assume that stock can be stored indefinitely to meet future demands. In practice there arise a lot of problems associated with the management of perishable inventories, where the infinite lifetime assumption is no longer reasonable. Fresh products, such as meat, poultry, dairy products, fruits and vegetables have a highly perishable nature. As a result the loss due to deterioration cannot be ignored. Rather than compromising on replenishment decisions, we investigate the impact of varying prices to influence demand. The existing literature dealing with this problem is dominated by either deterministic demands or single period stochastic models.

We consider a retailer facing stochastic demand for fresh food which deteriorates after a fixed period of time. Demand is price-sensitive and we analyse both the backorder and the lost sales situation in case of a stockout. The objective is to maximize expected profits as a difference between revenues and procurement costs. Besides charging a single constant price in every period and customers following either first-in-first-out or last-in-first-out product selection, we analyse the possibility to charge separate prices for each unit of an age category, which can either be static or change dynamically over time depending on the amount of initial inventories in each age category. As a further extension, we compare the above results to those obtained by ignoring perishability and charging a single price in each period (independent of the unit's age category) depending on the total amount of initial inventories.

After modelling the above mentioned problems as stochastic dynamic programs, we analyse the functional equations and discuss the structure of the optimal ordering and pricing policy. Due to the additional model complexity by joint pricing and replenishment, the optimal policy is not of the simple base-stock type which is already true for the pure perishable item inventory control problem. For reasons of applicability, though, we compare simple base-stock policies with an optimal policy. An extensive numerical study is conducted that illustrates the benefits of having the possibility to vary prices according to inventory levels compared to static pricing and the effect of joint pricing and replenishment.

Keywords: *Inventory management, pricing, stochastic demand model, perishable items*

ECONOMIC EQUILIBRIUM OF AN MRP SYSTEM INCLUDING DISTRIBUTION AND REVERSE LOGISTICS APPLYING MRP THEORY

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In a recent paper by the authors, "A Compact Representation and Optimisation of Distribution and Reverse Logistics in the Value Chain", the methodology combining input-output analysis and Laplace transforms used as a theoretical background for describing and analysing Material Requirements Planning, *MRP theory*, has been extended to systems with distribution networks and systems with remanufacturing. The current paper follows up on the previous paper by deriving economic equilibrium conditions for the system, such that demand and supply are made equal for material flows between the main sub-systems. Additionally, comparative static relationships are developed for studying the effect of parameter changes on the equilibrium state.

Keywords: *MRP theory, Laplace transforms, input-output analysis, economic equilibrium.*

A NOTE ON SAFETY STOCK CALCULATIONS FOR A PERIODIC ORDER SYSTEM

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A periodic-order inventory system is studied. At the beginning of each period P, a new order is placed, and after a lead time L the order arrives. This paper analyses the following question: What happens with the optimal safety stock if P changes to $2P$, $P/2$, $P/4$ or $P/8$ with the same demand and variations in demand? We wish to have the same low risk for stock-outs, independently of how often the replenishment takes place.

A number of rather complicated formulas for this problem have been presented in the literature; but we are attempting to derive some simpler rules of thumb.

The practical situation where this type of problem has occurred is in a production facility, where a cyclic policy (production rhythm) has been adopted. Different items are produced with a periodicity P. The company wishes to be "lean" and have as short a P as possible.

Initially, we assume a constant L and make different assumptions on the coefficient of variation of demand.

Keywords: *periodic order system, safety stock, stock-outs, replenishment periodicity.*

A HEURISTIC PROCEDURE FOR A DYNAMIC INVENTORY ROUTING PROBLEM

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We propose a Logistic Network where a central warehouse (vendor) distributes a single commodity to multiple geographically dispersed retailers (buyers) through a finite planning horizon consisting of *T* periods. Each retailer faces a deterministic and time-varying demand, which should be fulfilled at the beginning of each period and influences the replenishment policy at the warehouse within a Vendor Managed Inventory (VMI) framework. Furthermore, the maximum inventory level at each retailer is limited due to local storage constraints and the batches are delivered by a single capacitated vehicle. We also assume that the total cost function involves the following components: a unit holding cost per period and location, a transportation cost between each pair of distinct locations and a fixed shipment cost per period. When the fixed shipment cost is activated in one period, a unique route should be stated to distribute the corresponding delivery quantities to a subset of retailers. The model so stated can be seen as an extension of the classical Inventory Routing Problem to the case with time-varying demand, and hence it can be referred to as the Dynamic Inventory Routing Problem (DIRP). Accordingly, the goal is to determine a compromising inventory/distribution policy which guarantees the demands at each retailer are met on time without exceeding both local storage and vehicle capacities.

A TWO-ECHELON INVENTORY/DISTRIBUTION SYSTEM WITH LTL (LESS-THAN-TRUCKLOAD) DELIVERIES – MIXED INTEGER APPROACH

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The paper concerns a class of supply chain management problems called Joint Transportation-and-Inventory Problems (JTIPs). These problems are characterized by the presence of both transportation and inventory considerations, either as policy-variables or constraints. The two-echelon inventory/distribution system with LTL deliveries is considered.

The research presented in this paper aims at determining an optimal joined inventory/transportation policy. The mathematical modeling is applied to find the optimal solution to such defined JTIPs. The set partitioning formulation for solving the vehicle routing problem is incorporated into a discrete time, finite horizon inventory planning problem. Two algorithms will be discussed: the exact algorithm and the heuristic algorithm which solves this model with predefined quantities of delivery. As is shown in the paper, this approach allows us to take into consideration a lot of additional constraints such as the constant cycle of deliveries, route determinants, and the number of deliveries in the planning horizon.

The literature review on JTIPSs is concisely presented in the first part of the paper. Then a short description of the considered inventory/distribution system is provided. The main part includes major issues that occur while designing and implementing solutions in this area. Then the outline of the mathematical model formulation employed is given. The author concludes the article with a brief discussion of the results one of the empirical instances.

Keywords: *two-echelon inventory/distribution system, supply chain management, mixed integer programming*

INVENTORY MANAGEMENT AND CAPACITY RESERVATION UNDER SPOT MARKET PRICE UNCERTAINTY

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Procurement has always been a critical factor for the success of economic relationships between enterprises. With the growing importance of electronic commerce and global sourcing, new procurement opportunities have evolved. For instance, it has become a lot easier and quicker to purchase goods required to fulfil short-term demands independent from existing long-term procurement contracts. In many cases, long-term procurement costs are, on average, lower than the costs of short-term supply. However, in order to profit from this cost advantage often a long-term capacity reservation contract has to be negotiated. In this environment of multiple procurement options with differences in costs and flexibility, the process of coordinating the procurement activities has become more difficult. In detail, one has to decide if an enterprise is better off with long-term procurement contracts or short-term procurement or if a combination of both alternatives should be used.

This contribution focuses on the cost-effective management of the combined use of these procurement options. In our case, the short-term option is given by a spot-market with a random spot-market price (which is independent of the quantity procured), whereas the long-term alternative is characterized by a simple wholesale price contract with a capacity reservation level. The planning situation we consider gains further complexity by the fact that in addition to the stochastic spot-market procurement option also randomness of demand for the procured goods is taken into account. Under these conditions, the managerial task is to fix a long-term capacity reservation level and to decide period-by-period on how to combine the two supply options in order to profit from the cost savings of long-term procurement while still remaining flexible. Concerning the price variations on the short-term market, this flexibility can be used to benefit from low short-term price levels while the long-term contract is a means to hedge the risk of high prices.

In this research analytical results for inventory and capacity reservation management are developed if the decision rule applied is restricted to a simple two-parameter base stock policy. Furthermore, it is shown via stochastic dynamic optimization that the optimal policy is of a more complex three-parameter type with a price-dependent order-up-to level for short-term procurement. For this policy type a fairly simple heuristic is developed for determining the respective policy parameters. Finally, some numerical results are presented which give an impression on the performance of the heuristics developed for this inventory management and capacity reservation problem.

AN INVENTORY CONTROL PROBLEM UNDER PERISHABLE COMMODITY AND NO-PERISHABLE COMMODITY

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This paper considers an inventory problem with both perishable and non-perishable commodities under two types of customers and fuzzy shortage cost. Perishable commodity has only one period. There exist two types of customers. One is sensitive to the freshness and buys perishable commodity first and if perishable one is sold out, then buys non-perishable one. The other is sensitive to the price and so buys only non-perishable. Further we assume that shortage cost is fuzzy number and demands of both customer types are non-negative random variables and they are independent. First we calculate an expected total profit and seek some non-dominated ordering quantities since the profit becomes a fuzzy number and so usually there exist no optimal ordering in a sense of strictly maximizing the profit. Finally we discuss further research problem.

PURE AND RESTRICTED BASE-STOCK POLICIES FOR THE LOST-SALES INVENTORY SYSTEM WITH PERIODIC REVIEW AND CONSTANT LEAD TIMES

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We consider the notoriously difficult lost-sales inventory system with periodic review and constant lead time L. Motivated by exact results obtained in case of geometric demand, we present closed-form expressions which approximate the important performance measures of the base-stock policy for any demand distribution. In case of Poisson demand, the approximate expressions converge toward the exact ones for the related continuous-review system when the length of the review period goes to zero. Our expressions facilitate finding a good base-stock policy. We also introduce a new policy which improves the policy with base stock s by restricting the order quantities to be at most q. It can be implemented almost as easily as a pure base-stock policy. From a Markov chain, we compute the exact performance of the pure and restricted base-stock policies by the Gauss-Seidel method. Our numerical study demonstrates excellent performance of the restricted policy with s as the good base stock computed with our approximations and q as the fraction $\frac{s}{L+1}$ rounded to the nearest integer.

Keywords: *Base-stock policy; Lost sales; Markov chain; Periodic review*

AN IMPROVED ANT COLONY OPTIMIZATION FOR VEHICLE ROUTING PROBLEM

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Ant Colony Optimization method (ACO) is well known as a new swarm intelligence meta-heuristic which is found to be efficient to solve hard combinatorial optimization problems, such as Job Shop Scheduling Problem, Graph Coloring problem and Vehicle Routing Problem. ACO method, however, is pointed out to have some weak points compared with the other meta-heuristic methods. The most weak point of ACO method is that ACO has no means of escaping the trap of bad local minimum solution. The other meta-heuristic methods, Simulated Annealing (SA), Tabu-Search (TS) and Genetic Algorithms (GA), are equipped the definite means to escape the local minimum solution. Another weak point of ACO is that ACO is not equipped any efficient local search methods, so it takes many computational time by convergence. In this paper, we propose an improved ACO with the device of escaping from the trap of local minimum and with the local search method. The Vehicle Routing Problem (VRP) is the typical hard combinatorial optimization problem which determines a set of optimal routes for fleet of vehicles with minimum total traveling cost in order to satisfy a given set of customers. In this paper, we present an efficient solution method based on improved ACO for VRP.

Keywords: *Combinatorial Optimization Problem, Ant Colony Optimization method, Meta-heuristics, logistics system, Vehicle Routing Problem*

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PERIODIC INVENTORY CONTROL WITH STOCHASTIC DEMAND AND A MINIMUM ORDER QUANTITY

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In order to achieve economies of scale in purchasing, production or transportation many industries, for example chemical or apparel, use a minimum order quantity Q_{min}. As a result the flexibility to respond to demand is reduced and only amounts larger than Q_{min} can be ordered, produced or transported. The minimum order quantity constraint is often caused by technical constraints.

Up to now little effort has been devoted to the modeling and analysis of inventory systems working with minimum order quantities. Many researchers have studied reorder point batch policies, (s,Q)-policies, where orders are placed in batches to raise the inventory level above the reorder point s. Also a large body of literature is available on models with fixed ordering costs and fixed batchsizes, where (s, S) policies have been shown to be optimal. But it has also been shown that this class of policies is not optimal in case of a minimum order quantity (see Zhao and Katehakis (2006)).

In this paper we study a periodic review single stage inventory system with stochastic demand for a single product. In each time period the system must either order nothing or at least as much as a minimum order quantity Q_{min}. Since the optimal structure of an ordering policy with a minimum order quantity is complex, we propose a policy, which we have observed at a company we are working with. This policy is easy to implement and use, because it is only determined by a single policy parameter S. This parameter acts as reorder-level as well as order-up-to level. We show how to determine the optimal value of the policy parameter S such that the average holding and backorder costs are minimized by using a Markov Chain approach. Additionally, we derive simple formulae for the cost optimal policy parameter, which can easily be implemented within spreadsheet applications. The approach is to derive news-vendor-type formulae that are based on underage and overage cost considerations. In a numerical study we test the performance of the approximation for three different demand distributions: Poisson distribution, negative binomial distribution and an adapted (discretized) version of the gamma distribution. For each distribution scenario a full factorial experiment is conducted, seeking to cover a wide range of input parameters. We employed three levels for each of the 4 or 5 factors (leadtime, holding cost, mean demand and demand variability, minimal order quantity), resulting in 567 examples in total. Very small cost deviations (on average less than 1%) are observed compared to the optimal solution within the investigated class of inventory policies.

Keywords: *Stochastic inventory model, Minimum order quantity, Markov Chain, Newsboy Equation*

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SETUP STABILITY COMPARISON OF (s,S) AND (R,S) INVENTORY CONTROL RULES UNDER NON-STATIONARY STOCHASTIC DEMAND

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In stochastic inventory planning systems unfolding uncertainties in demand lead to revision of inventory plans. This results in different order release decisions in successive planning cycles, which in turn leads to instability in inventory plan, or so-called system nervousness (Vollmann et al., 1988). Inventory management involves application of various inventory control policies which are extensively investigated in terms of their cost performance. However, in systems with a low degree of flexibility, the cost of implementing revisions in setup decisions may overcome the advantage of using the cost-efficient technique. Thus, system nervousness, as a performance criterion, can be of high importance in assessing inventory control rules.

In terms of stability, stationary and non-stationary inventory problems have different characteristics. In the stationary demand case policy parameters are also stationary and therefore, the instability between two consecutive planning cycles reflects the instability of the whole system. On the other hand, in non-stationary systems policy parameters are determined in connection with each and every time period through the horizon, and consequently the measure of nervousness must take into account the instability among all consecutive planning periods. This difference may have significant effects on the stability performance of inventory policies in non-stationary demand environments. However, to the best of our knowledge, no work has been done on the measures of nervousness for non-stationary problems.

The (s,S) control policy has been shown to be cost-optimal under very relaxed assumptions in both stationary and non-stationary cases (Scarf, 1959; Iglehart, 1963). Heisig (1998,2001), and de Kok and Inderfurth (1997) have questioned the performance of (s,S) policy with respect to the nervousness criterion in the stationary case. Their research reveals that, in terms of nervousness (s,S) policy exhibits the worst performance among a number of policies considered. Different strategies for dealing with the problem of nervousness are examined by Blackburn et al. (1986). Their study also suggests a freezing schedule strategy which is based on encouraging setups in periods where they are scheduled previously. In this regard, (R,S) policy, in which the schedules are set, particularly for the timing of future orders with the associated order-up-to-levels provides a means of dampening the setup instability (Tarim and Kingsman, 2006).

In this paper, (i) we provide the grounds for measuring system nervousness in non-stationary demand environments, and (ii) gauge (R,S) and cost-optimal (s,S) type inventory control policies in terms of long-term setup oriented system nervousness. In order to achieve a sound comparison, we also consider (R,S) policy with a re-planning framework. We use a test set including a variety of demand patterns, coefficients of demand variation and costs for an assessment of setup instability. Numerical results indicate that (R,S) policy is clearly dominant to (s,S) policy in terms of stability performance, and cost penalty thereof is fairly insignificant on the whole. These show that (R,S) is an effective inventory policy and can

replace cost optimal (s,S) policy, especially for systems characterized by a low degree of flexibility to setup changes.

Keywords: *Inventory policies, Stability, Non-stationary demand*

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THE SINGLE ITEM NEWSBOY PROBLEM WITH BATCH-WISE DEMAND CLASSES

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We consider a single item newsboy problem, where the item can be sold to several demand classes, each of which has a fixed individual order size and a given frequency of occurrence. The revenue gained from fulfilling an order is proportional to the batch size of the demand class, and all orders which cannot be fully satisfied are lost. This problem has common features with several classes of the newsboy problem, such as, the newsboy problem with multiple demand classes (e.g. Sen and Zhang, 1999), the two-item newsboy problem with substitutability (e.g. Khouja et al., 1996), and the newsboy problem with cutoff transition size (e.g. Dekker et al., 2000). However, it has a particular difference. That is, because of the binding batch sizes of individual orders, the order is lost even if a small portion of the batch is not available. To the best of our knowledge, this problem has not been addressed before.

Regarding the given system, we can define three stages in which the inventory level is, (i) sufficient to satisfy the next order regardless of the batch size, (ii) sufficient to satisfy an order only if it has a small batch size, (iii) not sufficient to satisfy any order. Specifically, we concentrate on the second phase, and explore the effects of (i) inventory rationing policies, and (ii) advanced demand information.

The problem is originated from the batch processing industries, particularly, a multi-product batch processing system where all products are processed from a common raw material. The level of raw material inventory at any time is limited by the available storage tank capacity. Replenishments for raw material are only possible at pre-specified intervals of time and replenishment lead times are assumed to be negligible. Processing of raw materials into end-products is carried out by batch processing units which are dedicated to certain end-products. Batch sizes are fixed for all processing units, and therefore, orders require fixed amounts of raw material. With these settings, available tank capacity becomes the most important performance indicator. Therefore, we aim at determining the raw material storage capacity which guarantees a given service level for each end-product.

Since the replenishment intervals are fixed, and the lead time is negligible, this problem reduces to a newsboy problem, where the replenishment decisions given in a particular period do not affect the next one. However, the problem is still non-trivial because of the underlying complex stochasticity of the system. Therefore, we consider the problem with two end-products (i.e. with small and large batch sizes with various frequencies of each demand class), which enables us to explore the basics of the system. We investigate the effects of advanced demand information and possible basic control rules using first-come-first-served as a benchmark.

***Keywords**: Newsboy problem, Demand classes, Batch arrivals*

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A COMPARISON OF THE CONSTANT-ORDER AND DUAL-INDEX POLICY FOR DUAL SOURCING

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In practice, it can be frequently encountered that companies rely on two or more suppliers for their material procurement. Such dual-/multiple-sourcing strategies provide some flexibility with regard to demand handling, resulting in cost savings without compromising service. Having two suppliers available, the majority of materials can be replenished from the cheaper one, which usually has a longer procurement lead time (*regular supplier*). In case of peaks in demand, replenishment orders can be placed with the more expensive, but faster supplier (*emergency supplier*) in order to avoid future stockouts. Although many companies already employ dual sourcing, they are still asking for simple, yet effective policies to support their replenishment decisions.

In contrast to many single-sourcing models, where optimal inventory control policies are readily available, results for dual-sourcing models are limited to very special cases. So far, the optimal policy has mainly been derived for dual-sourcing models with a lead-time difference of one period between both suppliers. Nevertheless, several other policies have been proposed in the literature for more general settings. Two prominent ones are the constant-order and the dual-index policy. Under the constant-order policy, the order amount with the regular supplier is fixed in each period and the emergency order is determined according to a simple order-up-to logic. The dual-index policy, on the other hand, specifies two order-up-to levels, one for the regular and one for the emergency supplier. For the execution of replenishment orders, it also keeps track of two inventory positions. Such a policy represents a simple alternative to the optimal policy, which would require carrying a vector of inventory positions that covers the entire lead-time difference between the two supply options.

We analyze the above-mentioned policies in a periodic-review setting with stochastic demand and linear holding, backorder and procurement costs. For the first time (up to our knowledge), we present a comprehensive comparison between these two policies for deterministic lead times. Optimal policy parameters are found by a Markov Chain approach in case of the constant-order policy and by a simulation-based optimization procedure in case of the dual-index one. We provide a detailed analysis of the order processes both policies are inducing. Insights are drawn from an extensive simulation study. In terms of total system costs, we identify major drivers for the performance gap between the two policies. We find that with an increase in the lead time of the regular supplier, the cost difference between the two policies diminishes and the much simpler constant-order policy matches or even outperforms the dual-index one. As an extension, we discuss the impact of stochastic lead times on both policies.

Keywords: *dual sourcing, dual index, constant order, multiple suppliers*

A CONTINUOUS REVIEW INVENTORY CONTROL MODEL FOR PERISHABLE PRODUCTS HAVING A DETERMINISTIC LIFETIME

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This paper is motivated by the potential applications of perishable inventory control in the areas of consumer goods, pharmaceutical industry or blood bank management. The inventory of such products, characterised by a limited lifetime, should be managed carefully. Figures from industry outline the cost associated with the poor management of such perishable products: $30 billion of products are lost due to perishability in US grocery industry (Lystad et al., 2006).

The perishability issue leads also to stockouts that are induced not only from a forecast error in estimating demand but also from the fact that products are perished in stock. The economic importance of managing perishable products leads to substantial work in perishable inventory control literature. Investigations developed so far underline the difficulty of tracking the different-aged categories. Such settings require the development of complex dynamic programming approaches. Finding an analytical solution becomes challenging (Nahmias, 1982). To deal with this complexity, our approach is to propose a new approximation of the expected outdating products which modify an earlier study (Chiu, 95). Our paper investigates an approximate continuous review (r,Q) inventory policy for perishable products having a fixed lifetime. We derive approximate expressions of the key operating characteristics of the inventory system (such as the expected quantity of perished products, the expected inventory level and the expected shortage) and obtain a closed form long run average cost under positive lead time. The effectiveness of the model is tested by a simulation experiment implemented in Arena software. Numerical analysis is presented to illustrate the advantages of using the proposed policy comparing to the classical (r,Q) policy witch ignoring the perishability of products.

Keywords: *Inventory management, Continuous review, Perishable products, Simulation*

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OPTIMIZING THE STORAGE ASSIGNMENT IN A WAREHOUSE SERVED BY MILKRUN LOGISTICS

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The storage assignment problem involves the placement of a set of items in a warehouse in such a way that some performance or cost measure is optimal. We investigate this problem in the context of a warehouse served by milkrun logistics, i.e. vehicles circulating according to pre-defined schedules between the warehouse and the production departments of the plant. Since each milkrun cycle (vehicle) serves the material requirements of a different department, and each department produces different end products, different milkrun cycles have different probabilities of requiring an item. Requests are processed simultaneously by multiple human order pickers assigned to a number of zones in the warehouse.

Informally, order picking times can be reduced by placing high-runner items near to the entrance of the warehouse, and by storing items that are often ordered together close to each other. Technically, this problem is a special case of correlated storage assignment, where the organizational structure behind the correlation among ordering probabilities of different items is known and can be exploited by a mathematical model. We show that with appropriate approximations of the probabilistic formulae, the problem can be represented as a MIP, and can be solved by commercial software.

We demonstrate that minimizing the order cycle time (maximum of individual pickers' times) and minimizing the average picking effort (sum of pickers' times) are conflicting criteria. Our MIP allows controlling the trade-off between these criteria by minimizing a linear combination of the two, or minimizing one of them subject to an upper bound on the other.

A simple simulation environment has been developed to test the performance of the proposed approach on a detailed model of order picking in the warehouse. The novel strategy has been compared to classical cube-per-order index-based (COI) techniques in computational experiments. Experimental results show that our approach leads to an up to 36-38% improvement in either criterion compared to COI.

Keywords: *Storage assignment, warehousing, milkrun, mixed-integer programming.*

SEARCH FOR GOOD POLICIES IN A SINGLE-WAREHOUSE, MULTI-RETAILER SYSTEM BY PARTICLE SWARM OPTIMISATION

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The system we are considering consists of a single warehouse and a given number of retailers. The retailers are faced with a random demand for a single product. Each retailer can send an order for new product to the warehouse, which has an ample amount of product but a finite number of transportation resources (TUs). The TUs may belong to different classes (trucks, pickups, ships, etc.). Each TU class is characterised by its loading capacity, speed or transshipment time and costs – fixed and time-dependent costs as well as loading/unloading costs. At the retailers, which may have different distances to the warehouse, arises holding cost for inventory on hand and waiting and rejection cost for backlogged respectively rejected demand. Clients may be impatient and leave the waiting queue after a random time. The problem is to define for the warehouse an allocation policy of free transportation resources to retailer orders and for the retailers such ordering policies that minimise the long-run average cost in the system.

Obviously we can not expect to get an analytic solution for the described problem. Therefore we suggest combining simulation and optimisation. To apply the simulation optimisation approach we need a simulator for the considered system as well as an optimiser, which in our case is a variant of particle swarm optimisation (PSO). A problem solution is a vector whose components represent parameter values of the different policies of the warehouse and all retailers as e.g. the numbers s and S of an (s, S) ordering policy of a retailer. The simulator simulates the behaviour of the system for a given solution and returns an estimation of the corresponding long-run average cost. The basic idea of PSO is that the particles of the swarm can share information about the so far best solution and additionally each particle has an internal memory to store its best so far solution. The movement of each particle through the search space is then given by a trade-off between its current velocity, a movement in the direction of its local best solution (cognitive component) and the so far global optimum (social component).

In our paper we describe in detail the simulator as well as the PSO-approach. Finally we report on numerical experiments and give some hints for further developments.

THE STANDARD INDIRECT GROUPING MODEL TO OPTIMIZE THE PREVENTIVE MAINTENANCE OF A MULTI-COMPONENT MACHINE

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For several industrial systems, the maintenance policy involves many components; the cost of a joint-preventive action is considerably smaller than the total cost of similar maintenance actions if carried out separately, i.e. there is a gain in set-up costs. Basing on the inventory theory, we present a multi-grouping maintenance approach, allowing coordination of components replacement of a series system with economic dependence that can assist a maintenance manager in making an optimal maintenance plan. Goyal and Kusy [1] were the first to introduce the multi-item inventory control model in maintenance optimization.

The common planning approach used for multi-component manufacturing systems is the group/block replacement models. In the "Standard indirect grouping", each component is maintained at an integer multiple of a basic interval, allowing the coordination of components replacement. Finding optimal solutions is a mixed continuous-integer programming problem; so heuristic or numeric solutions must be developed. Several techniques, which were already studied for the inventory control model, were related to the deterioration-cost function denoting the expected cumulative deterioration costs of components, including failure costs, repair costs, operating costs, etc. The difficulty is proportional to the complexity of the form of this cost function; most authors assume polynomial form with the same degree for all components [2], this means that all components have the same degradation mode, which can be unrealistic. In other hand, when the smallest integer is larger than one, there would be some occasions where the system is not maintained "empty occasions" and consequently the set-up cost is not paid during these occasions. Some authors use a correction factor which may be computationally prohibitive.

Our indirect grouping approach is based on "minimal repair and partial periodic renewal" policy for the overall system. At each partial renewal, a group of components to be replaced is defined; as a result the partial renewals are different along the system renewal cycle. When all components are replaced simultaneously, we assume that the system is overhauled and becomes as new as good. The formulation is done in such a way that we haven't to introduce the degradation factor related to partial renewals (imperfect maintenance concept). A general failure rate for all components is assumed. The possible empty occasions are avoided, by selecting the smallest interval among all components intervals as the basic interval. A solution procedure based on Monte Carlo simulations with informative search method is proposed and applied to the optimisation of the replacement plan for an industrial system.

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A STUDY OF INVENTORY RATIONING WITH RESPECT TO ORDER SIZES

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There has been quite many studies of inventory control in presence of several (often two) customer classes. The aim of those studies is to design rationing rules concerning when to backlog the demand of the least important customer classes when the inventory level is critically low. In this study we will add a specific characteristic to distinguish the customer classes, namely size. Often one encounter that the larger orders received are "normal" routine replenishment orders of a customer while smaller orders can be categorized as some sort of "emergency" orders. Also often a customer, who makes a very large order, is very much aware of the inconvenience he creates, and is therefore more willing to wait some time before his order is served while a customer of a smaller order will tend to expect that he can be served immediately. We study an inventory system operated as a base stock system, with control parameter S. The demand process is a compound renewal process. Instantaneously, as the demand is registered, a replenishment order is issued having the same size as the registered demand. We assume all replenishments have a constant lead-time L. In addition to the control parameter S we also introduce the control parameters q and t. The parameter q distinguishes the order sizes into small and large orders. A small order is served instantaneously, while a large order is backlogged for t time units before it is served. Specifically, it means that if $t = L$ then we do not need the inventory to handle the large orders. We develop a solution procedure to compute optimal vales of S, q and t. The aim is to minimize the average physical inventory subject to a service level constraint, where the service measure is an aggregate (over the customer classes) order fill rate service measure.

A HEURISTIC ALGORITHM AND A SHORTEST-PATH REFORMULATION MODEL FOR A MULTI-PRODUCT DYNAMIC LOT-SIZING AND SHIPPING PROBLEM

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This paper analyzes a dynamic lot-sizing and shipping problem for multiple products that are transported from a warehouse (or a plant) to a retailer by common freight containers. The following assumptions are made: (i) each ordering lot in a period is immediately shipped in the same period, (ii) the total freight cost is proportional to the number of containers used, and (iii) demand backlogging is not allowed. The objective of this study is to identify effective algorithms that simultaneously determine production lot-sizes and a shipment policy that minimize the total cost consisting of ordering cost, inventory holding cost, and freight cost. It can be shown that this problem is NP-hard, and this paper presents a heuristic algorithm that exploits the properties of an optimal solution. Also, a shortest path reformulation model is proposed to obtain a good lower bound. Computational results from a set of simulation experiments are presented to evaluate the performance of proposed procedures.

Keywords: *dynamic lot-sizing, shipment scheduling, heuristic algorithm, shortest-path reformulation model*

INVENTORY COORDINATION FOR A DETERIORATING ITEM WITH QUANTITY DISCOUNT UNDER ASYMMETRIC INFORMATION

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Traditionally, as independent entities, members in a supply chain have little communication about their demand and inventory activities and prefer to maximize their own profits rather than consider the benefits of the whole supply chain. Therefore, one of the main issues of supply chain management is to establish certain effective and efficient coordination mechanisms to encourage the cooperation among members, and thus improving the overall performance of the supply chain.

Among various types of coordination mechanisms, quantity discount is the most popular one. It has been proved that quantity discount can induce the buyer to choose a higher lot size and make both parties better off than without any form of coordination. One of the basic implicit assumptions of most inventory models has been the infinite shelf life of products while in storage. That is, a product once in stock remains unchanged and fully usable for satisfying future demand. However, there are items such as highly fresh fruits, volatile substances, radioactive materials, etc., in which the rate of deterioration is very sensitive and its impact must hence be considered explicitly.

Another common assumption is that that the vendor has full information about the buyer's cost structure. In practical, it is not the case. It might be difficult for the vendor to get the information on the buyer's costs, such as setup cost, holding cost or opportunity cost. Intuitively, the more private information the buyer has, the more extra profits he can gain.

In this paper, the effects of deterioration and asymmetric information are both considered. The authors establish a model that a vendor supplies to a buyer a single product that always display the same deteriorating rate over lifetime and adopts quantity discount as coordination mechanism to optimize their order schedules. The optimal quantity discount contracts are respectively derived under full information and under asymmetric information, in which the buyer has the private information on his setup cost. With numerical study and sensitivity analysis, the authors compare these two situations and indicate that the buyer's total cost decreases while the vendor's cost increases under asymmetric information. Nevertheless, contracting is more efficient than no form of coordination. Also, the quantity discount and the costs of the buyer and the vendor will rise when the deteriorating rate becomes higher.

Keywords: *Supply chain management; Deteriorating item; Quantity discount; Asymmetric information*

HYBRID GENETIC ALGORITHMS FOR THE MULTI PERIOD INVENTORY ROUTING PROBLEM

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The coordination of the inventory management and transportation is often known as the Inventory Routing Problems (IRP). It is an important component of Supply Chain Management. The objective of IRP is to determine an optimal inventory and transportation policy that minimizes the total cost. The resulting inventory and transportation policies usually assign retailers to routes and obtain replenishment intervals and collection sizes for each retailer. The problem addressed in this study is a many-to-one distribution network consisting of an assembly plant and many geographically dispersed suppliers where each supplier supplies distinct product to the assembly plant. The problem addressed in this paper is based on a finite horizon, multi-periods, multi-suppliers and multi-products where a fleet of capacitated homogeneous vehicles, housed at a depot, transport parts from the suppliers to meet the demand specified by the assembly plant in each period. We propose a hybrid genetic algorithm based on allocation first, route second method to determine an optimal inventory and transportation policy that minimizes the total cost. We introduce two new representations. The first is based on a $N \times T$ binary matrix, where N and T are the number of suppliers and the number of periods respectively. It determines which supplier that needs to be visited in each period. The amount to be collected is calculated as $\sum_{l=j}^{k-1} d_{il}$, where d_{il} is the demand for product i in period l, and the next collection will only be made in period k. The second representation encodes a collection matrix that determines concurrently which suppliers to be visited and the amount to be collected from those suppliers in each period. To ensure that all the related constraints are not violated, a new crossover and mutation operators are introduced. Both algorithms embed a double sweep algorithm proposed by (Lee et. al, 2003) to cluster and route the suppliers. It is observed that the simple representation produces better results for medium sized problems. The second representation performs better in larger problems. It is also noted that due to the huge transportation costs, any attempt to reduce the inventory holding costs does not have any significant impact on the best solutions found.

THE JOINT REPLENISHMENT AND FREIGHT CONSOLIDATION OF A WAREHOUSE IN A SUPPLY CHAIN

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We have developed joint replenishment and consolidated freight delivery policies for a third party warehouse that handles multiple items in a supply chain. Two policies are proposed and mathematical models are developed to obtain the optimal parameters for the proposed policies. Four efficient algorithms are presented to solve the mathematical models for the two policies, and these are illustrated using a numerical example. The performance of the two policies with the parameters obtained from the proposed algorithms are then compared with the common cycle approach for 1600 randomly generated problems. The results show the robust performance of the proposed algorithm for both policies.

Keywords: *Joint replenishment problem; Freight consolidation; Heuristic algorithm*

COLLABORATIVE PRODUCTION PLANNING FOR A TWO-STAGE PRODUCTION SYSTEM

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This study considers the production and inventory management problem of a two-stage production system. This system produces several types of make-to-stock products through a batch production process and an assembly line production process. These processes are managed separately, but they share information about their production plans and shipping plan of the final products. The batch production process has a minimum batch size constraint caused by long setup time, and consumes a fixed lead time. On the other hand, the assembly line can produce different product types without a significant setup operation, and the lead time for assembly is negligible. Therefore, the assembly line may use all semi-finished product types in one period, while the batch production process can produce a limited number of types within the same period. Obviously this means that the production system inevitably involves high level of semi-finished inventories between two processes. The primal problem of this system is how to decide the optimal production plan for both processes that satisfies the given shipping plan with minimum cost, considering the production capacity and lot size constraints. Two mathematical programming models are developed. The first model involves the detailed decision variables of both processes, and can be regarded as a global optimization model. The other is a realistic approach to obtaining an acceptable production plan by dividing the problem into two models, i.e., assembly planning and batch production planning models. In addition, the assembly plan is determined hierarchically, i.e., the upper model decides the required capacity considering the shipping plan measured in production capacity over a longer planning horizon, and the lower model decides the detailed assembly plan under decided production time and detailed shipping plan over a shorter planning horizon. The objective of the batch production planning is to satisfy the planned assembly plan considering the overtime and inventory costs. The numerical computation revealed that obtaining the assembly plan first and then batch production plan incurred higher costs when compared with the solution of the global model, and the degree of the difference depended on the length of the planning horizon. Although the global model is superior in minimizing total cost, making a whole model is not realistic in our assumed environment. An ideal method is to consider the condition and constraint of batch production process when deciding assembly plan. In this study we realize this idea by incorporating the batch production plan when solving the lower level of assembly plan. The batch production plan used in this step is obtained from the shipping plan, and thus the final plan is determined after freezing the detailed assembly plan. These iterative steps can be seen as collaborative planning of two processes, and the performance of the proposed approach is investigated by numerical experiments.

Keywords: *production planning, two-stage, mathematical programming, batch process*

A DIFFERENT PERSPECTIVE ON CHANNEL COORDINATION: CARRIER-RETAILER CHANNELS

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We study a carrier-retailer channel with a single item with price dependent demand. More specifically, the retailer orders a particular item from an outside supplier and the carrier transports the retailer's orders. The profits of the channel members depend on the inventory and pricing decisions of the retailer as well as the freight rate decision of the carrier.

We consider two channel structures: (i) the centralized channel and (ii) the decentralized channel. In the first one, the goal is to set the retail price and the order quantity so as to maximize the total channel profit. In the latter,,the retailer and the carrier choose their own policy parameters—i.e., the retailer sets the retail price and the order quantity and the carrier sets the freight rate—so as to maximize their own profits. We model the decentralized channel as a Stackelberg Game. We study the efficiency of the two channel structures of interest through an extensive numerical study. Our numerical results reveal that in some instances the channel profit is positive only after centralization. Hence, the corresponding channel coordination problem is important for all practical purposes. In order to address this problem, we propose a linear price contract—where the retailer sets the retail price by allocating a markup on the freight rate and the wholesale price–and examine the efficiency of this mechanism for a win-win solution.

We provide results considering both a single planning period and an infinite planning horizon. These results allow us to evaluate the benefits of coordination for both short and long term interactions, and they validate the notion that coordination benefits are more pronounced in the long run. Considering the infinite planning horizon problem, we also analyze the effect of coordination on inventory levels.

We demonstrate that centralization reduces the prices, and, hence, increases the demand volume. However, the resulting increase in inventory levels is not as much as the increase in the demand. We also find that centralized channel profits are approximately 10% higher than the decentralized channel profits. This finding is comparable with the improvement obtained in the context of the classical supplier-buyer channel coordination problem. We also observe that although the benefits of coordination are not sensitive to the ratio of the transportation costs to the overall costs, they are more significant when the carrier's profit margin is low which is a typical situation in the transportation industry.

Keywords: *Channel coordination, inventory, transportation, game theory*

A TABU SEARCH FOR MULTI-COMMODITY CONTAINER TRUCK TRANSPORTATION

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Inland container transportation is the most important transportation problem and truck, train, and barge are used to transport containers in the local area. In this paper, we consider a truck transportation problem to transport containers (freights) between terminal and customers' places. It is assumed that there is one depot which has trucks and empty containers, one terminal, and several customers' places.

Both 40 ft and 20 ft dry containers are used and a truck can move two 20 ft containers simultaneously or one 40 ft container. Thus, the truck scheduling problem becomes more complicate than the case of one type among 40 ft and 20 ft containers.

All time (time windows) and amount of import and export freights between terminal and customers' places are given and we determine the truck schedule to satisfy the freight schedule and minimize the total traveling distance. For export containers (freights), pick-up and delivery time windows are assigned but only pick-up time windows for import containers are assigned. Thus, we consider trucks and empty containers as logistics resources, and we try to operate the resources economically and satisfy the logistics requirements. As a result of considering 20 ft and 40 ft containers together, the trucks have 8 different transportation states, contrasted with 3 possible states when we consider only 40 ft containers.

To build a mathematical model for the problem, we define a graph with vertexes and arcs. Based on the defined graph, we propose a tabu search algorithm and some numerical examples are studied to evaluate the performance of the proposed algorithm.

Keywords: *container; truck; time window; tabu search*

OPTIMIZING HYBRID SOURCING STRATEGIES FOR FASHION PRODUCTS UNDER DIFFERENT RISK PREFERENCES USING AN EXTENDED NEWSVENDOR MODEL

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Losses which result from uncertain demand appear in two ways: On the one hand as opportunity costs due to a lack of product availability; on the other hand as remainder of stock. The more imprecise the production and replenishment planning systems within a supply chain work, the more often shortfall quantities occur with particular product variants while other product lines suffer from overstockings. The resulting losses in forecast-driven supply chains are higher, the more dynamic, versatile and unstable demand characteristics are. Whereas demand for standard products (e.g. commodities) can be well predicted, high volatility hinders accurate demand forecasts for innovative products (e.g. fashion apparel, consumer electronics, etc.). Overstockings and shortfalls not only occur more often with innovative than with standard products, but also the consequences are significantly more serious: Innovative products are normally short-dated and sold in short selling seasons, which subsequently leads to lost sales if the consumer demand is not immediately satisfied. Besides, at the end of the selling season overstockings can only be sold in deficit. In the American apparel industry the loss in sales due to forced mark-downs are estimated to be more than 30%. Hence agile manufacturing and distribution networks are required which are able to react quickly to improved demand forecasts. However, the call for more agility in fashion supply chains should not be misunderstood: in the majority of cases it won't be optimal to substitute non-agile low-cost offshore supply completely with more expensive reactive onshore supply. Far more promising are hybrid sourcing strategies, which aim for supplementing the inflexible low-cost country sourcing with quick response manufacturing in a perfect manner.

We investigate these hybrid sourcing strategies using an extended single-product newsvendor model with two order points assuming normal distributed demand. At the early order point the demand forecasts are vague, but there is still enough time left until the beginning of the coming selling season to accept the long lead times of offshore supply. At the later order point the quality of the demand forecasts gets considerably better (e.g. a trade fair took place, purchasing agents of retail chains placed first orders), but the beginning of the selling season is now so close, that only more expensive onshore production capacities are fast enough to produce the (possibly needed) supplemental quantity in time. How large should the order quantities be for the offshore and the onshore supply? This question will be answered in this paper for risk neutral and risk averse decision makers. The risk averse behaviour will be described by an exponential utility function. Under realistic parameter ranges the optimal order quantities can only be numerically computed. Basic results of this paper are: As long as the onshore ordering costs are smaller than the selling price of the considered item, hybrid sourcing strategies are always preferable to an exclusive offshore approach. The more risk averse a decision maker is, the smaller will be the offshore order quantity. The general

impacts of price, cost and forecast parameters and different degrees of risk aversion on optimal ordering policies are discussed.

Keywords: *Newsvendor Model, Hybrid Sourcing, Quick Response, Fashion Products, Demand Forecasting, Risk Aversion*

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AN INTEGRATED EQUAL-LOTS POLICY FOR SHIPPING A VENDOR'S FINAL PRODUCTION BATCH TO A SINGLE BUYER UNDER LINEARLY DECREASING DEMAND

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This paper considers a supply chain in which a vendor supplies a product to a buyer. The vendor is about to manufacture the final batch of the product at a finite rate and then periodically ship the output to the buyer. The buyer then consumes the product at a linearly decreasing demand rate. Most previous work on this topic has been based on the assumption of fixed demand rate. Costs are attached to the manufacturing batch set up, the delivery of a shipment and stockholding at the vendor and buyer. The objective is to determine the number of shipments and sizes of those shipments which minimise the total cost - assuming the vendor and buyer collaborate and find a way of sharing the consequent benefits. We show how the optimal policy may be derived when the shipments size are identical. We illustrate this policy with numerical examples.

Much attention has been paid in recent years to managed supply chains, partly as a consequence of the relentless drive to lower costs and partly as a consequence of the facility for parties in the chain to share information electronically. A common feature is that one dominant member of the chain controls the flow of goods in the way that is deemed most efficient and a means is devised for the rewards of this integrated control to be shared between the members of the chain. Over the years mathematical models have been developed to describe the behaviour of such integrated systems and to determine optimal control policies. Because such systems are complex much of this research has been concentrated on deterministic models in a slightly idealised settings. The hope and expectation is that these models provide some degree of qualitative insight into the behaviour of more complex real-world problems, which generally involve levels of uncertainty.

The basic model considered here consists of a single vendor who manufactures the final batch for a product and then transfers the stock to a single buyer as a number of shipments. The buyer has to satisfy from the stock a linearly decreasing and continuous demand process for a finite horizon. There are costs associated with batch set-up, delivering a shipment, and holding stock at both the vendor and the buyer. The objective is to determine the shipment policy which minimises the total system cost.

Goyal (1977) was probably one of the first papers to investigate the integrated single-supplier single-customer problem. Bannerjee (1986) considered the vendor manufacturing for stock at a finite rate and delivering the whole batch to the buyer as a single shipment - a 'lot for lot' model. Goyal (1988) demonstrated how lower cost policies generally result from allowing a production batch to be split and delivered as a number of shipments. Lu (1995) set out the optimal production and shipment policy when the shipment sizes are all equal. Goyal (1995) demonstrated how lower cost policies sometimes result when successive shipment sizes increase by a ratio which is equal to production rate divided by the demand rate. Hill (1999) derived the form of the optimal policy if shipment sizes may vary. This consists a number of shipments which increase by the ratio used in Goyal (1995) followed by a number of equal-sized shipments.

Brosseau (1982) considered the optimal policy for a single level inventory problem when the demand rate is linearly decreasing and derived an analytical method for determining the optimal number of replenishments, the times of those replenishment and the corresponding optimum cost. After that several researchers investigated various approximate approaches to the problem. Recently, Goyal and Giri (2003) derived a simple rule by using a backward search method for determining the solution for the model with a linearly decreasing demand rate. However, most of the work on linearly decreasing demand is concerned with a single stocking point.

A common assumption that has been made is that the demand rate at the buyer is fixed over an infinite horizon. In this paper, demand up to time zero is constant, at rate a. From time zero to time H the demand rate decreases linearly from a to zero. At time zero the vendor is about to manufacture the final batch, at rate P. The size of the batch Q will be exactly what is required to meet all remaining demand (up to time H). At time zero the buyer holds a quantity x in stock. The quantity x could be the amount at the beginning of the previous production cycle based on a fixed shipment size policy, or it could be based on a variable shipment size policy or it could just be an arbitrary amount of stock. However, there remains some demand for the product to be satisfied but this tails off (linearly). Just before the equipment for manufacturing the product is dismantled there is one final opportunity to make enough stock to meet all the remaining demand.

The problem is to find the optimal number of shipments and sizes of those shipments. Two possible policies would be for the shipments to have all the same size but not evenly spaced in time or to be evenly spaced in time but not equal in size. In this paper we consider the first case. For the globally optimal policy, the shipments would vary in both size and frequency.

Keywords: *production, inventory, single-vendor, single-buyer, linearly decreasing demand*

DYNAMIC PROGRAMMING FOR COMPUTING NON-STATIONARY (R,S) POLICY

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In this work we propose an efficient dynamic programming approach for computing (R,S) policy parameters under non-stationary stochastic demand and service level constraints. (R,S) is a popular inventory control policy typically employed for damping planning instability (Silver, 1998). Early works in the area were heuristic (Silver, 1978; Bookbinder and Tan, 1988). Sox proposed a static control policy (Sox, 1997). The first complete approach for computing (R,S) policy parameters was proposed by Tarim and Kingsman (Tarim and Kingsman, 2004) in the form of a MIP model. Tempelmeier extended this MIP formulation in order to consider different service level measures (Tempelmeier, 2007). Tarim et al. proposed an efficient CP approach for solving large instances (Tarim et al., 2008). The approach proposed in this work outperforms Tarim et al. CP approach. Our computational experiments show that this new approach is also more scalable, being able to efficiently handle much longer planning horizons. Our method exploits the well known concept of State Space Relaxation (SSR). A filtering procedure and an augmenting procedure for the state space graph are proposed. Starting from a relaxed state space graph our method tries to remove provably suboptimal arcs and states (filtering) and then it tries to efficiently build up (augmenting) a reduced state space graph representing the original problem. Our experimental results show that the filtering procedure and the augmenting procedure often generate a small filtered state space graph, which can be easily processed using dynamic programming in order to produce a solution for the original problem.

Keywords: *Inventory Control; Non-stationary (R,S) Policy; Stochastic Demand; Dynamic Programming; State Space Relaxation; State Space Filtering*

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INVENTORY RATIONING IMPACT ON ORDER FULFILLMENT PERFORMANCE MANAGEMENT

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In many inventory settings, companies wish to provide different levels of service to different classes of customers. Customer-differentiated service levels may be motivated by the perceived relative importance of certain customers or by specific contractual relationships in which a defined service level has been guaranteed. To provide differentiated service levels a company has to determine the amount of inventory dedicated to each individual customer class. In the relevant literature, approaches to inventory rationing are typically based on cost and revenue measures. It is assumed that a company can assign a customer specific revenue or penalty cost to any order or unit of demand filled or unfulfilled. However, it is a difficult task to accurately determine the monetary implications of fulfilling individual orders; companies therefore commonly base inventory decisions on service level and fill rate measure targets. If such non-monetary measures are employed, the decision maker faces a decision making problem with multiple objectives: reserving some portion of the available inventory for priority customers may have a (disproportionate) detrimental impact on the performance of the overall system. The decision maker therefore has to evaluate the (non-linear) trade-off between the benefits of ensuring higher service levels for prioritized customer classes and the decrease in the overall performance. The research presented in this paper addresses the problem of setting appropriate inventory reservation levels for different customer classes based on non-monetary performance measures such as service levels and fill rates.

We consider a basic problem setting which is based on a specific industry problem: An OEM of DSL telecommunications equipment sources all of its products from Electronic Manufacturing Service (EMS) providers with manufacturing facilities located in low cost production regions. The OEM uses a three month rolling forecast from its customers to determine replenishment orders. Once the orders are placed, the EMS provides firm delivery dates with a lead time of eight weeks. In many instances, there is a significant deviation between the forecast provided by the customers to the OEM and the actual orders received. This often results in situations wherein the OEM anticipates that the available inventory will not be sufficient to fulfill all customer demand on time. Due to the long replenishment lead times, however, he has no way to remedy this anticipated shortage by re-ordering. In order to maintain the on-time delivery performance for certain key customers, the OEM resorts to reserving a portion of the available inventory only for these high priority customers. Based on this example, we model a single period inventory reservation problem with two customer classes. We derive exact expressions for different performance measures (service level and fill rate) both for the individual customer classes and for the overall inventory system. These expressions allow us to determine the conditions under which it is prudent to pay the price of losing some overall system performance to achieve a certain performance for prioritized customers. Our results can be generalized to many industry settings in which a company has to regularly ration a perishable resource among different customer classes.

Keywords: *inventory rationing, multiple demand classes, order fulfillment performance management*

ECONOMIC LOT SCHEDULING PROBLEMS WITH NEW AND DIFFERENT COST APPROXIMATIONS

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This paper considers scheduling the production of several different items on a single machine with constrained capacity, commonly known as the Economic Lot Scheduling Problem (ELSP). Nilsson and Segerstedt (2008) show that even for ELSP problems with high utilisation it is possible to find a feasible solution (fulfilling feasibility conditions from Eilon (1962), Goyal (1975), Segerstedt (1999)), but the real inventory holding cost is often higher than the common used approximation. This is because the production of an item has to start before the inventory of the same item reaches zero, to avoid a future shortage of the same item. The common cycle solution always presents the "right" inventory holding cost; but diversifications of the frequencies may not accomplish what it promises. Most traditional approaches for the ELSP consider only the sum of the setup cost and inventory holding cost and provide cyclic schedules that minimize this sum. In practice, there are not only costs for setups and inventory holding, but also costs for operating the production facility due to e.g. electricity, service, maintenance, tools, operators etc, which depend on the number of hours the facility is operating per working day (cf. Brander and Segerstedt (2008).

Our investigations in this paper find a solution method that can evaluate different schedules due to different frequencies, and find the right inventory holding cost without the common approximation and combine it with a facility time variable cost as in this paper. We start from an idea from Cooke et al (2004) and van der Sluis (2006). A mixed integer programming (MIP) problem that from a common time period and integer number of frequencies for each item minimises costs and avoids shortages. But we try to avoid MIP and its long calculation times, when in our case to find the best solution several MIP calculations have to be done after each other.

Keywords: *ELSP, Multi products, Single machine, Capacity constrained; Production facility cost*

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TWO WAREHOUSE INVENTORY MODELS FOR DETERIORATING SEASONABLE PRODUCTS

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In this paper an order level two-warehouse inventory system seasonable products with time varying deterioration rate is considered. When the item under consideration is a seasonable one, the manager may purchase more quantity than can be stored in own warehouse (OW). Therefore, the excess quantity is stored in a rented warehouse (RW). Further, the inventory costs (including holding cost and deteriorating cost) in RW are usually higher than those in OW due to additional cost of maintenance, material handling, etc. The rented warehouse generally provides better preserving facility than the owned warehouse resulting in a lower deterioration rate for the goods. To reduce the inventory costs, it will be economical to consume the goods of RW at the earliest. As a result, the firm stores goods in OW before RW, but clears the stocks in RW before OW.

Additionally, it is observed that the demand of seasonable products increases at the beginning of the season up to a certain moment (if customers are satisfied with quality and price) and then stabilizes to a constant rate for the remaining time of the season. The term "ramp type" is used to represent such a demand pattern. In this paper a general ramp type demand rate, with its variable part being any positive function of time is considered. The unsatisfied demand is partially backlogged at a rate, which is any non-increasing function of the waiting time. This two-warehouse inventory problem is studied under two different policies. The first policy starts with an instant replenishment and ends with shortages and the other policy starts with shortages and ends without shortages. The optimal ordering quantity is derived for both the above mentioned policies.

Keywords: *Inventory; Deterioration; Ramp type demand; Two-warehouses; Shortages*

CLOSED-LOOP CONTROL OF STOCHASTIC LINEAR SYSTEMS WITH CONTROL CONSTRAINTS

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We consider the implementation of a production-inventory related plan in a stochastic environment. The plan may be the output of a linear or mixed integer programming based optimization model where various sources of uncertainty are taken as deterministic, or it is the result of negotiations between different supply chain partners. Due to the fact that the plan is executed in an environment with uncertainties, a tracking-type model is used where both the deviations from the target plan and the activities to keep the plan on track have quadratic costs. We model the problem as a Linear-Quadratic-Gaussian (LQG) control problem subject to control constraints, i.e., optimal control of a stochastic linear system with a quadratic objective function and constrained control variables.

The unconstrained version of our problem is a well studied one in the control theory literature. The LQG optimal control theory provides one of the central results of linear system theory. This result is the separation theorem (or the so-called certainty equivalence principle) implying that the optimal control strategy can be separated in two parts: one state estimator which produces the best estimate of the state vector of the system from the observed outputs, and one linear control law which gives the control as a linear function of the estimated state. Unfortunately, this result does not carry over to the Constrained LQG (CLQG) problem, and as pointed out by Toivonen [1983], no explicit solution exists. We have developed a suboptimal algorithm that achieves a closed-loop control for the CLQG problem by using Lagrange multipliers dynamically. Our technique is based on the approach by Chow [1992, 1993, 1997]. The main advantage of our approach over all the approximate methods proposed in the literature is that we obtain a closed-form result. In terms of ease of implementation, the derived algorithm is comparable with that of the well-known unconstrained LQG optimal control rule. Moreover, we prove that the proposed algorithm outperforms the saturated LQG control that omits the control variables, which is commonly used in the literature (e.g., Aviv Submitted to ISIR 2008 15 March 2008 [2007]). We conduct a numerical study on the problem of inventory balancing in distribution systems to demonstrate the performance of our approach. The results indicate that, under control constraints, the new algorithm significantly reduces the loss compared with that of the simple saturated LQG algorithm.

Keywords: *Linear Quadratic Gaussian control; constrained control variables; quadratic performance index; Lagrange multipliers*

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BATCH ORDERING PROBLEM IN MULTI ITEM TWO ECHELON SPARE PARTS INVENTORY CONTROL SYSTEMS

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In this study we deal with a multi-item two-echelon spare parts inventory control system in which the central warehouse operates with reorder point/order quantity (Q,R) policy whereas local warehouses implements one-for-one replenishment. In this environment we study the batch ordering problem of the corresponding system. There are two common approaches in determining policy parameters. One approach is the sequential approach in which the order sizes are determined at first, in most cases by EOQ-rule, then given the order sizes, the reorder level for the central warehouse and the basestock levels for the local warehouses are determined. The other approach is the simultaneous approach in which all the control parameters of the system including the order size are optimized simultaneously. The former one is suboptimal, but due to its simplicity, very common in the spare parts business. One aim of this study is to test the performances of the sequential approach and the simultaneous approach in a multi-item setting. In order to accomplish this goal we need an exact solution procedure for the problem. The second aim of this study is to propose an exact solution procedure for the problem. The procedure is based on using the Lagrangean dual bound in a branch and bound procedure. Later this solution procedure is used to test the performances of the sequential approach and the simultaneous approach. By doing so, we hope to evaluate the value of "optimal solution" of batch ordering problem in a multi item two-echelon distribution system.

LOT-SIZING DECISIONS UNDER DYNAMIC QUANTITY COMPETITION

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In recent years, the coordination of marketing and operations decisions has received a lot of attention. In particular, determining the "right" selling price is a complex task which not only requires detailed customer information but also accurate information about the own operating costs, the supply structure, and competitors. An important aspect in this regard is the ability to adapt. To charge the customer the right price at each point in time, the company must be able to change prices at minimal costs. Whereas for retail stores price adjustments are rather costly, online stores, e.g., Amazon.com or Walmart.com may change their prices nearly costless which provide new challenges in the applicability of dynamic pricing strategies.

We consider a deterministic continuous-time Cournot competition problem on a market consisting of two competing retailers. At each time t, both retailers decide on the output level $_i D$, i=1,2 taking into consideration that the market price is sensitive to the total output $D=D_1+D_2$. It is assumed that the market price is a commonly known decreasing, concave, and twice-continuously differentiable function of the total output. Besides the output decision, the retailers have to optimize their procurement policy depending on the respective cost structure. For each replenishment order, retailer 1 faces both fixed and variable purchasing costs. On the other hand, retailer 2 faces no fixed ordering but only variable purchasing costs. Following the assumptions of the classical EOQ model, retailer 1 places replenishment orders in batches of size Q every T periods. Retailer 2, however, follows a Just-in-Time strategy due to zero fixed replenishment costs. We assume that both retailers are allowed to change their output continuously over time. As a consequence, the market price may change continuously as well. Each retailer maximizes his average profit per time unit taking the competitor's decision into account.

We develop a differential game where both retailers repeatedly interact over the order cycle, i.e., each retailer chooses his output (control variable) being aware of the output of his competitor. The output decision of retailer 1 is not only influenced by the competitor's output but also by his current inventory level (state variable). Since the inventory level decreases over an order cycle, the optimality conditions change continuously. It is assumed that for all t both retailers choose their output simultaneously. We derive some structural properties regarding the existence and uniqueness of an open-loop Nash equilibrium and analyze the optimal output strategies of both retailers. We show that the output strategy of retailer 1 is decreasing over an order cycle. This strategy leads to an inventory reduction right after an order which lead to lower holding costs. Furthermore, we show that although retailer 2 follows a JIT replenishment policy, he continuously increases his output due to batch ordering of retailer 1. Thus, retailer 2 increases his market share whereas retailer 1 decreases his market share over an order cycle.

Keywords: *dynamic pricing, inventory control, competition, differential game.*

THE COST OF RELAXING THE ASSUMPTION OF NON-STATIONARITY ON STOCHASTIC DEMAND

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A variety of models have been formulated to solve inventory control problems under stochastic demand characterized by different environmental assumptions. One of these distinguishing features is expressed by the stationary vs non-stationary dichotomy. Although, non-stationary demand assumption is more realistic for many real world problems, it is not usually adopted in real life applications due to the high computational complexity of corresponding models. Less computational and modeling complexities of stationary policies make them indispensable in many real life applications. However, the use of a stationary policy as an approximation for a non-stationary one, when demand has a non-stationary pattern, is sub-optimal with respect to expected cost. This paper aims at investigating the additional cost incurred by relaxing the demand assumption of nonstationarity and giving some inference about under which circumstances stationary models provide good approximations for non-stationary models.

We consider stationary and non-stationary (s,S) policies. Through out the paper it is assumed that the total cost function is comprised of fixed ordering, proportional unit, inventory holding, and shortage costs. We assume that there are no lost sales and replenishment lead time is zero. Period demand is a normally distributed random variable with different mean values in different periods, but the same coefficient of variation.

Approximate stationary replenishment plans are obtained by means of two orthogonal approaches. The first approach is based on the idea of computing the best stationary demand value representing the given non-stationary demand; in other words, converting the original non-stationary demand pattern into an approximate stationary one. Once the best stationary demand pattern is determined, the corresponding stationary plan can be computed easily using the well-known Zheng-Federgruen algorithm. The second approach is based on computing the optimal static policy when demand is non-stationary. In this approach, we find the optimal static (s, S) policy parameters giving the minimum expected cost under non-stationary demand. The cost performances of both approximate stationary plans are gauged on using an extensive test set and managerial insights are provided.

Keywords: *(s, S) Policy, Stationary Demand, Non-Stationary Demand*

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ESTIMATING THE OBSOLESCENCE RISK FROM DEMAND DATA

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An important contribution to the costs of inventory consist of the costs of stocks becoming obsolete. In literature, a number of models have been proposed that take this aspect into account in the inventory control. Few case studies, however, are available of applications of these kinds of models. Important information such as guidelines on how to estimate the parameters of these models is not available to practitioners. This paper aims at solving some problems regarding the use of inventory models including obsolescence. In particular we describe a statistical method that can be used to estimate the risk on obsolescence for parts.

The research was conducted at an original equipment manufacturer delivering spare parts to the equipment users. We will show using spare parts data from the manufacturer that obsolescence is an important problem. Because of this, it was decided that it would be worth it to include the notion of obsolescence in the inventory model. To this end a very simple Markovian demand model was adopted that includes the possibility of demand "dropping dead": the demand is healthy for an exponential amount of time, after which demand drops dead and inventory is obsolescent. In addition to parameters also needed in case of stationary demand processes, this demand model has one additional parameter that can be directly interpreted as the risk of obsolescence in the near future: the expectation of the length of the healthy demand period.

We propose a simple method that can be used to determine the risk on obsolescence. The method is based on making groups of spare parts. For these groups, the risk on obsolescence is estimated using the behaviour of similar groups of spare parts in the past. The method thus uses demand data as main information source, and can therefore be applied without the use of an expert's opinion. The application of the method at the company will also be discussed. We will give numerical values for the risk on obsolescence obtained with the method, and the effects of these values on inventory control will be examined. Finally, we qualitatively investigate the conditions under which the method can be applied. Strong points and limitations of the method will be discussed.

Keywords: *Sudden death, inventory control, spare parts, obsolescence, case study.*

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A NEW LOT-SIZING HEURISTIC FOR MANUFACTURING SYSTEMS WITH PRODUCT RECOVERY

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We consider a manufacturing system with product recovery. The system manufactures new items as well as remanufactures the returned items. The remanufactured/recovered items are as good as new and satisfy the same demands as new items. The demand rate for new items and return rate for the recoverable items are deterministic and constant. The relevant costs are linear holding costs for the new/serviceable items and the recoverable items, and fixed setup costs for both manufacturing and remanufacturing processes. No backlogging of demand is allowed. The problem is to determine the timing and the lot sizes for the manufacturing and remanufacturing setups so as to minimize the long-run average cost per year.

Teunter (2004) had proposed two types of policies for the problem. In the (1, R) policy, in each cycle, there is one manufacturing setup followed by R remanufacturing setups and in the (P, 1) policy each cycle has P manufacturing setups and 1 remanufacturing setup. Teunter develops heuristics to evaluate the cost of the (1, R) and (P, 1) policy and recommends choosing the better among the two policies. In the above policies, P and R are restricted to be integers to facilitate implementation and this may lead adjustment in the lot sizes and an increase in cost.

In this paper, we consider a class of policies (P, R) where in each cycle, there are P manufacturing setups and R remanufacturing setups. Rather than have P manufacturing setups followed by R remanufacturing setups, we interleave (or intersperse) the setups of the manufacturing lots and the remanufacturing lots in such a way that the buildup of the recoverable inventory is minimized. We develop two interleaving based (P, R) policy heuristics for the problem. In the first heuristic, the manufacturing lot size, Q_P, as well as the remanufacturing lot size, Q_R, are always kept fixed over time. In the second heuristic, we allow the lot size for remanufacturing, Q_R to be different in different setups in a cycle.

We then compare and numerically evaluate the proposed heuristics with the best of the (1, R) and (P, 1) heuristic.

Keywords: *Product recovery, lot-sizing, EOQ, interleaving*

ANALYSIS OF PURCHASING ACTIVITY WITH DISCOUNTED CASH FLOW INVENTORY MODELS

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The classical economic order quantity model has two types of costs: ordering and inventory holding costs. Inventory holding costs are out-of-pocket costs, i.e. it does not influence the cash flow. In our approach we investigate the purchasing and ordering process with discounting. Our research question is, whether the net present value formulation or the average cost formulation is better for the approximation of purchasing costs. To answer the question we apply the basic models of inventory management.

The model has the following form:

$$I_t = I_{t-1} + P_t - R_t, \quad (t=1,2,\dots T)$$

$$I_t \geq 0, P_t \geq 0 \quad (t=1,2,\dots T)$$

$$\sum_{t=1}^{T} \frac{1}{(1+r)^{t-1}} \cdot \left[F(I_t) + G(P_t)\right] \rightarrow \min$$

The parameters and variables of the model:

- R_t the cash requirements in the tth period,
- r discount rate,
- T length of the planning horizon,
- I_t cash level in time t,
- P_t transfer in period t.

The cost functions are:

$$F(I_t) = \begin{cases} f_1 \cdot I_t & I_t \geq 0 \\ f_2 \cdot I_t & I_t < 0 \end{cases},$$

and

$$G(P_t) = \begin{cases} g_1 \cdot P_t & P_t \geq 0 \\ g_2 \cdot P_t & P_t < 0 \end{cases}.$$

The model is a simple deterministic cash balance problem. We will analyze the optimal solution of this model.

Keywords: *Net present value, discounted cash flow, inventory models, purchasing*

PRODUCTION CONTROL AND ORDER ACCEPTANCE FOR A MULTI-PRODUCT INVENTORY SYSTEM WITH A STRICTLY CAPACITATED RESOURCE

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This paper tackles the design of the production and inventory control of a multi-product system with a strictly capacitated resource. Set-up times and set-up costs are insignificant. The production throughput time is small, smaller than each of the customer order lead times. So, in principle it is possible to produce make-to-order. However, the limited production capacity and the demand fluctuations cause congestion. Allowing inventory in some of the more common products is an attractive possibility to buffer the fluctuations. There are also products, however, that remain make-to-order. For such products one has to take care that the production throughput time is kept within the customer order lead time. Order acceptance is also important in balancing requirement and availability. For part of the products there is no choice in this respect; the customer order lead time is commercially enforced. For another part of the products it may be possible to postpone or reject the customer order. There is a reward per accepted customer order and there are inventory and stock-out costs. In playing with inventory and order acceptance, it is possible to balance the cost of keeping inventory, the utilization rate and the due date reliability or stock-out cost.

We develop a two-level control approach. The highest level uses only (*product*) aggregate information to control the order acceptance and the total production. The lowest level allocates the production to the individual items. This is a very common control scheme (see e.g. Meal, 1978 or Bemelmans, 1986). Ideally this lowest level uses only very short term information (*myopic*).

The aggregate control is based on results for the single-product system (see Wijngaard, 2004 and Wijngaard & Karaesmen, 2007). The optimal production policy for the set-up free, single-product system with positive customer order lead time is rather generally an order base-stock policy. The standard base-stock policy looks at the inventory itself, the order base-stock policy looks at the *modified inventory*, that is the inventory minus the complete order book (Gallego & Ozer, 2001). An order base-stock production policy is optimal for the unrestricted capacity case (see Hariharan & Zipkin, 1995), but also for the case with a restricted capacity as long as the customer order lead times are not too long (see Wijngaard, 2004 and Wijngaard & Karaesmen, 2007). Applying an order base-stock policy implies aggregation over *time* of the customer orders. For long customer order lead times this time aggregation leads to problems. It is necessary then to add a more detailed check that takes into account the due dates of the accepted customer orders. The order base-stock production policy, combined with this production check in case of long customer order lead times, performs well for the single-product case.

Here we show that it is possible to use this policy also for the aggregate level in the multi-product system. In case of many products and differences between products, aggregation becomes cumbersome generally. That is why we combine this two-level approach with a fast-mover/slow-mover approach. Aggregation may be restricted to the fast-movers, giving priority to the slow-movers. The claim that is developed in this paper is that this control approach

leads to close to optimal policies. The main method of study is simulation. Wherever possible we use analytical results. But the complexity of the system limits the contribution of analytical methods.

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AN ITERATIVE APPROACH TO ITEM-LEVEL TACTICAL PRODUCTION AND INVENTORY PLANNING

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In this paper, we propose an iterative approach to jointly solve the problems of optimizing tactical safety stock placement and tactical production planning. These problems have traditionally been solved in isolation, even though both problems operate in the same decision making space and the outputs of one naturally serve as the inputs to the other. For simple supply chain network structures, two stages and one or many products, we provide sufficient conditions to guarantee the iteration algorithm's termination. Through examples, we show how the algorithm works and prove its applicability on a realistic industrial-scale problem.

Keywords: *Inventory; Production; Hierarchical planning; Supply chain management*

ESTIMATING SPACE REQUIREMENT FOR OUTBOUND CONTAINER INVENTORIES IN PORT CONTAINER TERMINALS

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This study proposes a method for estimating space requirement for outbound containers. In most cases, the productivity of the container terminal is represented by the productivity of the vessel operation which consists of discharging & loading operation. The arrival rate of outbound containers for loading tends to be increased rapidly around vessel arrival time. The storage space for outbound container must be allocated in advance for the efficiency of loading operation. For the allocation, we must consider the forecasted arrivals of containers and the changes in space availability resulting from departures of vessels. Also the limitation on the total storage space must be considered. The outbound containers can be grouped by stowage patterns in the ship, which classify the containers into the groups by the type (full or empty), the port of discharge, and the size. Both the storage strategy and the size of storage space for each group affect the result of the productivity of the vessel operation. We analyze the impacts of various storage strategies on the productivity of the loading operation for outbound containers. Also various space reservation methods for randomly arriving containers are proposed. We analyze how the size of the space reservation affects the performance of loading operations and proposes the best method for the space reservation. The mathematical model is proposed for allocation the space for the reservation among the various container groups. Also a simulation study is performed to determine the size of reservation space and the time of allocation. Based on the selected reservation method, formulas are suggested for estimating the space requirement for various different conditions on vessel arrivals and composition of containers. Regarding the space allocation of outbound containers, Taleb-Ibrahimi *et al*. (1993) have suggested a method for allocating the temporary storage space and the designated storage space, which are assigned to each vessel. The trade-off is used between the cost of the temporary storage space and the cost of relocating the containers. Kim and Park (2003) proposed a dynamic space allocation method to minimize the total container delivery distance between the storage blocks and the vessel berthing location. Zhang *et al.* (2003) suggested a similar method for the space allocation, though they considered the workload imbalance in advance. Previous studies addressed the problem for allocating the storage space for outbound container of only a single vessel. Unlike the previous studies, we analyze impacts of various different space allocation strategies on the operation productivity and the space requirement and then propose a method to determine the total storage space requirement for outbound containers. The method in this paper may be used for the design of a container terminal, also for satisfying the requirement on the productivity of the loading operation.

Keywords: *Space requirement, outbound container inventory, container terminal*

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OPTIMAL INVENTORY CONTROL OF EMPTY CONTAINERS IN INLAND TRANSPORTATION SYSTEM

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In this paper, we deal with an inventory control problem of empty containers in inland transportation system. In Inland container transportation system, we transport freights (containers) between terminal and customer's places by trucks, trains and barges. Empty containers are the important logistic resource and shipping companies try to operate and manage empty containers efficiently. Because of trade imbalance between hub ports, empty containers should be transported from surplus area to shortage area periodically [2,3,4]. However, it is very difficult to forecast the demand of empty containers exactly and we need to build efficient way to control (order or sending) the empty containers. In this paper, we consider a hub area, assume the stochastic demand processes, and propose efficient inventory policies to control empty containers. First, we assume that the demand per unit time is an independent and identically distributed random variable. To cover the demand, we order the empty containers to other hubs based on (s, S) inventory policy with leasing (zero lead time) in which if we have no empty container, we lease the empty containers required [1]. For the leased containers, we should return the number of empty containers leased to the leaser after the given period. Second, we consider a stochastic demand in which the mean and variance of demand fluctuate in time and propose a reasonable policy. Simulation is used to estimate the expected cost rate of the given policies and a genetic algorithm is proposed to obtain the optimal control policies. Numerical examples are studied.

Keywords: *Empty Container, Inventory level, Simulation, Genetic Algorithm*

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MULTI ECHELON SUPPLY CHAIN: THE NEWSBOY PROBLEM WITH MIDPERIOD REPLENISHMENT

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The newsboy problem developed earlier by Hadley and Whitin (1963) is considered one of the most important inventory models of the present time.

Newsboy problem applies in a broad array of settings: fashion apparel retailers often must submit orders well in advance of a selling season as well as the replenishment of perishable food supplies in super-markets.

In the traditional newsboy problem a decision maker orders inventory before one period selling season with stochastic demand. If too much is ordered, stock is left over at the end of the period, whereas if too little is ordered, sales are lost: this is the common scenario of the well-known newsboy problem.

In this paper we have studied a variant considering a multi-echelon newsboy problem where items pass multiple distribution sites in series and/or parallel before the customer finally acquires them. In addition we will take into account the following adjustment to the problem: we consider two opportunity to order inventory one before the selling season, and a second with additional costs during the selling season. Lead time of order replenishment for the first and for the eventually second shipment are considered equal to zero.

In the traditional newsboy problem the only critical issues is the amount of the inventory procured while in the studied multi-level variant it is important to highlight that also the relative value of the supply chain's inventory between the supplier and the retailer is important as well.

Main finding of the work is that the multi-echelon newsboy problem can be reduced to a set of single-echelon newsboy problems.

OPTIMAL TRUCK SCHEDULING IN INLAND CONTAINER TRANSPORTATION WITH TIME WINDOWS

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In this paper, we deal with a truck scheduling problem in inland container transportation. There are three types of locations; a container terminal, customers' places and depots. The container terminal and customers' places are the pick-up and destination areas simultaneously of import and export freights, respectively. Depots are support places where trucks and empty containers are located. Thus, trucks and empty containers are logistics resources to be used for transportation of freights (containers) between the container terminal and customers' places. All time (pick-up and delivery time windows) and the amount of import and export freights between terminal and customers' places are assumed to be given. We would like to determine the truck schedule to satisfy the freight schedule and minimize the total unprofitable traveling time. In this paper, we also consider the reposition of empty containers between depots.

First, we build a multiple directed graph to formulate the truck scheduling problem mathematically. In the graph, a vertex denotes a sequence of activities for each import container or export freight and arcs denote activities between vertexes. Based on the graph, a mathematical model for the optimization problem is formulated and a heuristic algorithm is proposed. Finally, some numerical examples are studied to evaluate the performance of the proposed algorithm.

Keywords: *container transportation; empty containers; graph; heuristic algorithm*

4.
SPECIAL STREAM ON DEMAND FORECASTING FOR INVENTORY MANAGEMENT

CENTRALISED DEMAND INFORMATION SHARING IN SUPPLY CHAINS

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This research explores Centralised Demand Information Sharing (CDIS) in Supply Chains. CDIS is an information sharing approach where supply chain members forecast based on the downstream member's demand.

Bullwhip Effect, a demand amplification phenomenon, shows that as the demand moves upstream in supply chains, its variability increases. Many papers in the literature show that, if supply chain members forecast using the less variable downstream member's demand, this amplification can be reduced leading to reduction in inventory cost. These papers, using strict model assumptions, mainly discuss three demand information sharing approaches: No Information Sharing (NIS), Downstream Demand Inference (DDI) and Demand Information Sharing (DIS). The mathematical analysis in this stream of research is restricted to the Minimum Mean Squared Error (MMSE) forecasting method.

The motivation for this research arose not only to model a less restrictive supply chain, but also to improve the above approaches based on forecasting principles and ordering methodologies. In this research, apart from using the MMSE forecasting method, we also utilize two non-optimal forecasting methods, Simple Moving Averages (SMA) and Single Exponential Smoothing (SES). The reason for their inclusion is the empirical evidence of their high usage, familiarity and satisfaction in practice.

We first fill the gaps in the literature by generalizing the upstream demand translation for ARIMA (p, d, q) for SMA and SES. Then by using less restrictive assumptions, we show that the DDI approach is not possible while the NIS and DIS approaches can be improved. The two new improved approaches are No Information Sharing – Estimation (NIS-Est) and Centralised Demand Information Sharing (CDIS). It is argued in this thesis that if the supply chain strategy is not to share demand information, NIS-Est results in lesser inventory cost than NIS. On the other hand, if the strategy is to share demand information, the CDIS approach may be used which results in lesser inventory cost than DIS.

These new approaches are then compared to the traditional approaches on theoretically generated data. NIS-Est improves NIS while CDIS improves the DIS approach in terms of the bullwhip ratio, forecast error, inventory holding and inventory cost. The results of simulation show that the performance of CDIS is the best among all four approaches in terms of the above performance metrics.

Finally, the empirical validity of the new approaches is assessed on a two year, weekly sales data of a European Grocery Store. Empirical findings and theoretical findings are consistent regarding the performance of CDIS.

This research, thus, concludes that the inventory cost of an upstream member is reduced when they forecasts are based on using a Centralised Demand Information Sharing (CDIS) approach.

Keywords: *Demand Information Sharing, Forecasting, Inventory*

AN INVESTIGATION OF PERIODIC STOCK CONTROL HEURISTICS FOR INTERMITTENT DEMAND ITEMS

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Typically, the inventories related to intermittent demand patterns are managed through periodic stock control solutions, though the specific policy selected for application will depend upon various parameters including the degree of intermittence (slow/fast intermittent demands) associated with the Stock Keeping Units (SKUs) under concern. Many periodic stock control policies have been proposed in the academic literature since the 1950s to deal with differing demand patterns. In particular, the periodic order-up-to-level (T, S) policy has attracted considerable attention and it is a very appealing one from a theoretical perspective since it is simple, close to optimal and reflects to a great extent real world practices. Under this policy, the determination of the optimal order-up-to-level necessitates a hypothesized demand distribution but this constitutes a very difficult decision in the presence of intermittence.

Some periodic (s, S) stock control heuristics have also been proposed in the academic literature that are built explicitly upon specific distributional assumptions. Although their implementation is not as easy as that related to the (T, S) policy they may still be perceived as computationally affordable. In addition, various studies (e.g. Sani and Kingsman, 1997) have demonstrated their robustness in an intermittent demand context. The heuristics that have attracted most of the attention in the academic literature are: the Power Approximation (Ehrhardt and Mosier, 1984), the Normal approximation (Wagner, 1975) and the Naddor's heuristic (Naddor, 1975).

In this paper, all above discussed methods are first presented, along with the rationale for their consideration for intermittent demand SKUs, followed by a detailed analysis of their empirical performance. A comparison of these methods is conducted based on a large spare parts demand data set from the automotive and aerospace industries. The experimental structure and the simulation related details are outlined along with a discussion of the forecasting method employed for estimating the demand parameters. The out-of-sample results indicate the superior performance of the various methods for differing degrees of intermittence and the investigation under concern allows insight to be gained on stock control and demand classification related issues for such SKUs.

Keywords: *Inventory Heuristics, Forecasting, Demand Distributions, Simulation*

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A SYSTEMATIC APPROACH FOR DEMAND FORECASTING AND EFFICIENT REPLENISHMENT IN A HIGH-TECH RETAIL CHAIN

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The supply chain environment has changed in the last few years; uncertainty and variability in customer demand has increased due to the proliferation of products, the heightened expectations of customers and the decreasing product life cycles. Especially, high-tech products are characterized by a short life cycle, increased variety, volatile demand and quick obsolescence. Their typical demand pattern consists of rapid growth, maturity and decline phases. Thus, demand forecasts are unlikely to be accurate, leading to product shortages and lost sales. Under these circumstances, the appropriate application of demand forecasting methods and of an efficient replenishment policy are key issues in effective inventory management to satisfy the customers' expectations while keeping minimum inventory levels. Little is published on how these issues are handled in practice, while we haven't come across an empirical study of the demand forecasting techniques' performance in the case of a high-tech retail chain. This paper tries to address this gap.

An experimental approach is proposed for addressing demand forecasting and efficient replenishment in a high-tech retail chain. This approach is systematic and consists of three core phases: selection and evaluation of the demand forecasting model, integration of the model with the chain's replenishment policy, and application of the two models in a pilot program. The approach is illustrated through a case study involving a telecommunications organization that operates a wide retail chain of shops selling high-tech telecommunication and mobile telephony products. In this context, the Holt's (trend-corrected exponential smoothing) demand forecasting model is selected, as it is found to be more accurate after evaluation. Then, the model is integrated with the periodic replenishment policy of the high-tech chain. Finally, there is a 4-week pilot program in 8 shops.

Thus, the proposed systematic approach is evaluated in practice. The results show that the demand forecast is reliable and the replenishment process functions efficiently, in most of the ordering cases. Moreover, since the customers have been proved tolerant towards low product availability, the high-tech chain should focus on keeping stores' inventory level down, instead of trying to be more and more responsive to customers' expectations. In addition, most Out-Of-Stock cases in the shops have been found to be happening due to inventory shortage in the central warehouse. Therefore, the chain should keep the stores' inventory level down, but instead focus on improving the replenishment procedure and the inventory management of the central warehouse.

This case study is useful for the retail chains in handling demand forecasting and efficient replenishment, with the objective to assist counter demand uncertainty and improve product availability while keeping minimum inventory levels.

Keywords: *retail chain, demand uncertainty, forecasting, replenishment*

BOOTSTRAPPING FOR INTERMITTENT DEMAND: THEORY AND PRACTICE

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Intermittent demand items pose a significant challenge for inventory management systems. The systems must contend with a paucity of data and irregular demand sizes, leading to distributions of demand that may not be well represented by standard distributions such as the Poisson or the Negative Binomial.

An alternative approach, known as 'bootstrapping', consists of re-sampling historical observations many times, and then constructing a bootstrapped cumulative distribution function. Two approaches have been suggested. The first consists of re-sampling blocks of data, of length equal to the lead-time, thereby capturing any auto-correlations in the data directly. The second consists of re-sampling individual observations and then employing a Markov transition matrix to model a first-order Markov process for the incidence of demand. An additional refinement is to 'jitter' the demand sizes, to allow for the generation of bootstrapped values not observed in the historical data.

This paper includes a critical review of the procedures for estimation of the elements in the Markov transition matrix. It is shown that, when employed in an inventory context such as an Order-Up-To (OUT) system, the estimates are biased. Corrections for this bias are derived. The 'jittering' approach is compared to a Kernel Density Estimation method, and it is shown that the kernel approach has some desirable properties.

The final section of the paper consists of the simulation of an Order-Up-To inventory system, based on a large real-world demand data set, of the various approaches to bootstrapping, including a comparison with some benchmark techniques such as Croston's method. The results allow insights to be gained on the relative benefits of these approaches.

THE EFFECT OF FORECASTING ON COMPANIES' PERFORMANCES

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Introduction and research background: Demand forecasting has always been a relevant issue for manufacturing companies. In particular, over the years, practitioners and academics have devoted their attention to techniques and tools that can be adopted to improve forecast accuracy (Wright et al, 1986; Armstrong, 2001; Caniato et al., 2002).

Despite the plethora of studies on this issue, debate is still open of whether the adoption of forecasting techniques is always efficacious in improving forecast accuracy. In particular, during the last decade, several authors have challenged the assumption that: 'the more adoption of complex forecasting techniques – the better the forecast accuracy'. On the one hand, many authors attempted to demonstrate that the efficacy of forecasting techniques in improving forecast accuracy depends on the fit between the type of technique adopted and the context (Sanders and Manrodt, 2003; Wright et al., 1996; Makridakis et al., 1998). On the other hand, some researchers suggested that forecasting technique adoption is not enough to improve forecast accuracy (Moon et al., 2003; Armstrong). Forecasting management is a complex issue, that includes decisions on information gathering processes and tools (e.g., what information should be collected, how it should be collected), organizational approaches to be adopted (e.g., who should be in charge of forecasting, and which roles should be designed), interfunctional and intercompany collaboration for developing a shared forecast (e.g., using different sources of information within the company or supply network, joint elaboration of forecasts, etc.), and measurement of accuracy (e.g., using the proper metric and defining proper incentive mechanisms).

In addition, it is important to consider that, even if in the literature much of the discussion on the impact of forecasting on companies' performances has centered on forecast accuracy, empirical evidence demonstrates that forecast accuracy is just one of the reasons that lead companies to improve forecasting process (Barratt and Oliveira, 2001; Småros, 2007). In fact, a more structured forecasting process gives companies the opportunity to better understand market dynamics and customers' behaviours, reduce uncertainty on future events, and guide salespeople. In turn, this can have a severe impact on cost and delivery performances. Thus, some doubts can be expressed concerning whether the relationship between forecasting and forecast accuracy is the only relevant to be studied. Despite this, studies investigating the direct impact of forecasting on other performances are few and far between.

Aim of the paper and methodology: This paper intends to fill these gaps, by analyzing in detail the relationship between how forecasting is conducted and companies' performances. The relevant forecasting variables here considered, as they can significantly impact on performances, are:

- the *techniques* that can be adopted to improve forecast accuracy (i.e. the extent to which structured techniques, both quantitative and qualitative, are used)
- the *information* that can be combined to elaborate forecasts (i.e. the extent to which data and information from different sources are used) and
- the *role* of forecasting in supporting decision making within the company (i.e. the extent to which decisions within the company are based on forecasts).

Analyses on the impact of these variables on companies' performances are conducted by means of data collected by the Global Manufacturing Research Group (GMRG). The GMRG coordinates an extensive data gathering process regarding manufacturing practices in several countries all over the world. Data is available from 343 companies in 6 different countries (Austria, Ghana, Hungary, Italy, Korea and Poland). The sample is distributed among different companies' sizes and industrial sectors all belonging to the manufacturing and assembly industry; and is mainly constituted of medium size companies but also small and large ones are represented.

Preliminary findings: Preliminary analyses show that having a structured forecasting process may positively impact on forecast accuracy. This emphasises the attention that companies are paying towards proper design of their forecasting process; thus highlighting the importance of organization and managerial issues in demand forecasting.

The empirical analysis provides also evidence of the impact of forecast accuracy on cost performances. Quite interestingly while the relationship with cost performances is significant, this is not true for delivery performances. This means that the relationship between accuracy and delivery performances is probably more complex and the analysis of context factors (demand variability, production systems, etc) highlights reasons for this relationship.

A further interesting result of this research is that forecasting variables have a direct impact on cost and delivery performances. This finding confirms that companies often improve forecasting process not only for reducing forecast errors, but also for other reasons, such as for better managing product life cycles, promotions, or relationships with customers. This, in turn, leads to improved cost and delivery performances.

The next step of this research will be investigating whether forecasting variables can interact and influence companies' performances with a "synergistic" effect.

Keywords: *demand forecasting, GMRG, accuracy, cost and delivery performances, hierarchical regression*

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FORECASTING AND CONTROL IN MULTI-ITEM MULTI-ECHELON SYSTEMS

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In this paper we present a class of control policies called Synchronized Base Stock (SBS) policies that enable operational management of multi-item multi-echelon systems. The control policy is derived from a structural mapping of the original multi-item multi-echelon network into a collection of divergent decision node structures. These structures depend on both the Bill Of Material and the lead times of individual items. These structures unambiguously define the entities to be forecasted and over which time periods these forecasts should be made. In addition to this, the divergent decision node structures enable to incorporate the concept of item-customer specific lead times, which enables a unified treatment of the Customer Order Decoupling Point (CODP) concept. This implies that MTS, ATO, MTO and ETO can be dealt with in exactly the same manner. Furthermore it is shown that the parameters of the SBS policies can be efficiently optimized. A number of case studies are presented, where the SBS policies have been implemented.

CALCULATING SAFETY STOCK – IMPROVEMENT OF EXISTING METHOD

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Markets become more demanding everyday and companies are adjusting in different ways. Nowadays, many companies put a lot of their energy and finance in setting right level of safety stock, reduce related expanses and work more rational with their assets. Companies are aware of high importance of safety stock and they set it in many different ways. With help of technology, the companies managed to develop many concepts for calculating optimal level of safety stock. Unfortunately, there isn't any universal method, which can give us the optimal level of safety stock. Because of this, many companies set their level of safety stock in relation to actual sell in the past year. This method can be useful for smaller companies but when we try to set safety stock for bigger company, we found out how complex this calculation can be.

In our paper, we try to improve an existing method for calculating safety stock for one of the companies. To calculate safety stock by the existing method we have to rely on sales in the previous year. At the beginning we have to divide yearly sales into 14-day periods and mark them by the number of pieces per period. After that, we have to sort the quantities by ascending value of sale and include service level according to the policy of the company (ABC classification). Finally, we have to calculate safety stock, where the lead time, the difference between value at the 98th (or 90th) percentile and average sales and predicted growth of sales is taken into account. We propose the method which will reduce the costs of having safety stock and keep service level according to the policy of the company (as it is set in the existing method). The proposed method is based upon the Herrin's method, where we additionally optimize the forecast with regard to smoothing and initial parameters. In order to compare existing and proposed method we derive a cost model which calculates the costs according to demand on market in year 2007.

From the results, we prove that proposed method is more efficient than existing one. At the moment, the proposed method can reduce the costs and keep service level as it was set in existing method. If the safety stock would be calculated by proposed method, the costs would be lower (comparison with existing method) by approximately 12,75 %. Because of differences between existing and proposed method, the proposed method has a potential for improvement and reducing the costs even more (the growth is not yet included in the calculations, universality of the method…). By including mentioned parameters in proposed method we are sure that we can reduce the expenses related with safety stock and give the company a chance to become more competitive in relation with other companies.

A LAGGED DEMAND SUPPLY CHAIN

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This research considers a situation that the market demand information available for a supply chain is delayed, or lagged. The impact of this lagged demand information is quantified by using a serially linked two-level supply chain. It is assumed that each player exploits the order-up-to ordering policy. As the market demand model, a first-order autoregressive (AR(1)) process is assumed. The leadtime and the lag time (t) are constant over the time. The lagged market information and other necessary information are shared with the second level player. The impact of the information lag and forecasting methods on the total inventory cost and the production cost is considered.

We will show that in a single-level supply chain case, a conditional expectation of the demand over the lead-time plus the review period (this conditional expectation is called as "*MMSE forecast*" herein) does not provide the minimum value of the net stock variance. This is contrast to the finding of Vassian (1955) and Hosoda and Disney (2006). It is shown that when $t > 0$, a conditional expectation of the demand over the lead-time plus review period and t yields the minimum variance of the net stock levels. This conditional expectation is denoted as "*optimum forecast*". Interestingly, if the optimum forecast is exploited, the impact of the lead-time and that of t on the variance of the net stock levels become identical. In other words, the impact of delay in information is not the same as delay in replenishment, if a non-optimal forecast is made.

In the case of a two-level supply chain, the MMSE forecast outperforms the optimum forecast. We also show that when the MMSE forecast is used, a trade-off relationship between the total inventory cost and the production cost will exist in terms of t: if the value of t is reduced, the total inventory cost will decrease but the production cost will increase – and vice versa. Thus, for example, if the major concern of a supply chain is the production cost, reducing the value of t may not be a good course of action. Finally, we will propose a new forecasting method which can break through this trade-off relationship even though $t > 0$. This method is inspired by our previous work (Hosoda and Disney, 2007). Numerical analysis suggests that by using this new method, both the total inventory cost and the production cost can be improved at the same time.

Keywords: *Information delay; supply chain; order-up-to policy; MMSE forecast; AR(1) demand*

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DECISION SUPPORT USING DEMAND FORECASTING SYSTEM IN PRIVATE RESTAURANTS

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According to investigation of Statistics Bureau of Ministry of Public Management, Home Affairs, Posts and Telecommunications, the number of private and company restaurants decreased 0.9% from 1999 to 2004. As the breakdown, the number of private restaurants decreased 10% and that of company restaurants oppositely increased 6.3% [1]. In a word, the private restaurants are in crisis situation because of the company restaurants. The company restaurants investigate a condition of location enough when they open a new restaurant. On the other hand, the private restaurants cannot investigate enough because they cannot easily change their location [2]. In addition, the company restaurants can reduce a cost by a large amount of batch stocking, original stocking management by the demand forecasting system, and the shift management of the employee, etc...and variously important information is systematized, reasonable management is performed compared with the private restaurants. Actually, it is impossible for the private restaurants that large amounts of batch stocking like the company restaurants. The hearing investigation shows that the private restaurants depend on the intuition and the experience about the demand forecasting. As having investigated by various papers, the demand forecasting system for the private restaurants has not been found. Therefore, as one of the strategies, we research the demand forecasting for the private restaurants, construct decision support system as a tool that supports the decision-making in the private restaurants, and show the effectiveness by the case study. A demand forecasting system consists of moving average method, exponential smoothing method, and nearest neighbor method. At first, moving average method is used to give the first impact to the managers. Secondly, exponential smoothing method is not used a fixed parameter as a constant of a conventional method but used α as a variable in this paper. Lastly, nearest neighbor method is used not only simple past data but also new data. Those methods show the past data included in the data file, three forecasting values led by them, and the square errors between the forecasting value of t-1 period and its actual value to the managers. As a result, they can decide the demand forecasting for themselves. To verify the effectiveness of the demand forecasting system, we discuss to compare the result of the forecasting system with the result of the intuition and the experience by the data of sales on between 42 periods from 45 periods. As a result, the values of the demand forecasting system are better than the ones of the intuition and the experience as shown in Table 1. This result shows to be able to decide reasonable amount of stocks and lead cost reduction by using the demand forecasting system.

Table 1 - The result of the intuition and the experience and the forecasting system

t-period	Actual value	The intuition and the experience	The intuition and the experience based on the forecasting system
42	571,240	540,000	585,000
43	626,430	580,000	620,000
44	574,590	600,000	585,000
45	583,260	570,000	590,000

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ASSESSING DEMAND FORECASTING PRACTICES IN B2B ENVIRONMENT

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Demand forecasts are needed as input in many managerial decision areas, such as purchasing, capacity planning, production planning and inventory management. Majority of former forecasting studies focuses on forecasting techniques and forecast error, but in the recent years there has been a new emphasis in forecasting literature. Companies are facing increasingly uncertain and lumpy demand, for which reason applicability of quantitative forecasting techniques suffers. To cope with this development, qualitative forecasting techniques and collaborative information sharing in the supply chain have gained more interest.

Especially in industrial markets, where the number of customers is typically fewer than in consumer markets, there are more potential information sources to be used as a basis for forecasts, and therefore selecting and applying the right forecasting method can be complicated. For this reason, more attention in research should be paid on the managerial side of forecasting.

Most of the research dealing with forecasting practice relies on surveys, and the focus is on techniques that are used. More profound case studies reveal that many companies are falling short of best practice in forecasting. There are some potential reasons why this happens: demand forecasting does not have a crucial role for the company, theory of forecasting does not sufficiently cover the problems of real life, gains of effective forecasting is overlooked, or there are problems in implementing and organizing effective forecasting. Finding the true reasons for not applying best practices will help in pointing out areas development both in forecasting practice and theory.

In this paper, we present a framework for assessing the demand forecasting practices in industrial companies. Our framework covers four dimensions of forecasting management: 1) purpose of use, 2) functional involvement in creating the forecast, 3) forecasting approach, 4) performance and its measurement. The framework aims at describing the forecasting practices of industrial companies, and identifying potential conflicting or incomplete views inside the organization.

It is assumed that conflicting or incomplete views disturb the demand management process, and therefore revealing such issues is important when developing the forecasting process. This framework will serve as a research tool in such field studies that aim at enhancing understanding about the managerial challenges of demand forecasting. For companies, the framework serves as a tool to understand the status of its sales forecasting process and to identify ways to improve those processes. The framework is tested in empirical setting.

***Keywords**: Forecasting practice, forecasting management, supply chain*

ADIDA: AN AGGREGATE/DISAGGREGATE APPROACH FOR INTERMITTENT DEMAND FORECASTING

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Intermittent demand appears sporadically, with no demand at all in many periods of the time-series. One way to avoid this type of intermittence is by aggregating data into less frequent time periods, i.e. instead of having monthly data to keep your records at a quarterly level. This will potentially lead to non-intermittent series that would allow the use of a large variety of models as to prepare point and density forecasts. However, the usefulness of those quarterly forecasts, will be questionable, as the data and forecasts are monitored at monthly level in order to serve various operational needs (ordering, replenishment etc). Thus a formula for the derivation of monthly forecasts from the quarterly forecasts is needed.

This new idea, form now on called ADIDA (Aggregate Disaggregate Intermittent Demand Approach), is quite an intuitively appealing approach as it allows to aggregate data up to the level where no intermittence is occurring. At this level a far more advanced arsenal of forecasting methods is available relative to the variations of Croston's method - that are the standard in the intermittent demand literature. Simple mental heuristics or advance probabilistic models can be later used as to disaggregate point forecasts at the original levels of time periods. In essence, the approach is captured in three steps: aggregate data – forecast aggregate series – disaggregate forecasts. Serious issues should be addressed before the usefulness of this approach becomes clear: the level of aggregation might not be compatible with the operational needs of the company under consideration, the aggregation might end up in a much less frequent series or too short series (from weekly to annual data), etc; however the simplicity and methodological attractiveness of the proposed method, necessitates the empirical and theoretical investigation of the properties of this approach.

In this paper ADIDA is evaluated versus the most established forecasting methods for intermittent demand data: Naïve, Simple Moving Averages, Simple Exponential Smoothing, Croston's method, and SBA, the Syntetos & Boylan de-biased optimal version of Croston's approach. The comparison is performed on 3000 real intermittent demand data monthly series from the automotive industry as well as 6000 more simulated series. Various metrics are presented over a forecasting horizon of up to six months, including bias estimators (ME and MsE), accuracy metrics including relative errors as the relative geometric root-mean-square errors as well as the newly defined scaled errors (MASE, MdASE). Finally an inventory performance evaluation is conducted across the multiple demand forecasting contenders. The results from ADIDA are quite promising with most eminent the reduced bias and the comparable to SBA forecasting performance.

Keywords: *Aggregate-Disaggregate, Intermittent Demand, Forecasting, Bias, Accuracy, Stock Control*

DEVELOPMENT OF TRADING AGENT FOR DYNAMIC SUPPLY CHAIN MANAGEMENT

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Today, there are several markets in cyber space where companies trade electronically with the advent of new Information Technology. On the other hand, the most important thing in trades is negotiation. So, in order to support current business practices as well as new ones on the Internet, the systems need an ability to negotiate.

While, Supply chain management is concerned with planning and coordinating the activities of organizations across the supply chain, from raw material procurement to finished goods delivery. In today's global economy, effective supply chain management is vital to the competitiveness of manufacturing enterprises as it directly impacts their ability to meet changing market demands in a timely and cost effective manner. With annual worldwide supply chain transactions in trillions of dollars, the potential impact of performance improvements is tremendous. While today's supply chains are essentially static, relying on long-term relationships among key trading partners, more flexible and dynamic practices order the prospect of better matches between suppliers and customers as market conditions change. Adoption of such practices has proven elusive, due to the complexity of many supply chain relationships and the difficulty of effectively supporting more dynamic trading practices. TAC-SCM (Trading Agent Competition-Supply Chain Management) was designed to capture many of the challenges involved in supporting dynamic supply chain practices, while keeping the rules of the game simple enough to entice a large number of competitors to submit entries. In this paper, we have developed and implemented the algorithm based on 2007 TAC-SCM game rule.

Keywords: *Supply Chain Management, Automated Negotiation, Trading Agent Competition-Supply Chain Management*

REDUCING THE MEAN SUPPLY DELAY OF SPARE PARTS USING LATERAL TRANSSHIPMENTS POLICIES

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Lateral transshipment has been studied lately as a promising policy for increasing the performances of multi-echelon spare parts inventory system. By lateral transshipment spare parts can be moved from one location with excess inventory to another location, at the same echelon, in shortage, with the aim of reducing supply delays of spare parts. This paper examine the relative effectiveness of two lateral shipments approaches in reducing the mean supply delay (MSD) of a non repairable item, with respect to a classical policy of no lateral shipments. A simulation model of a two echelon supply network has been implemented and an experiment has been performed by varying different parameters of the supply network, such as the number of warehouses (locations at the lower echelon), the supply lead time from the central depot, the spare parts demand uncertainty, and the size variability of the warehouses. Results show appreciable reductions of MSD when lateral shipments are allowed with respect to the classical policy, in almost every network configuration.

Keywords: *Lateral transshipment, spare parts, inventory pooling.*

THE EFFECT OF USING ESTIMATED PARAMETERS IN AN (R,S)-INVENTORY CONTROL SYSTEM UNDER NON-STATIONARY DEMAND

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The influence of using estimated demand parameters on the performance of an inventory control system is an intriguing subject. Recent research has been performed on this phenomenon assuming stationary demand data and knowing the type of the demand distribution. This paper tries to extend this research to non-stationary demand data. Therefore, a way to generate non-stationary demand data from normal and from gamma distributions using one extra parameter is suggested.

The first model is closely related to an Arima(0,1,1) demand process. The demand, $\{d_t\}_{t=1,2,\ldots}$, is generated as follows:

$$\begin{cases} \mu_1 = \mu & d_1 = \mu_1 + \varepsilon_1 \\ \mu_t = \left[\mu_1 + \alpha_n \sum_{k=1}^{t-1} \varepsilon_k\right]^+ & d_t = \left[\mu_t + \varepsilon_t\right]^+, \; t = 2,\ldots \end{cases}$$

Here $0 \le \alpha_n \le 1$ determines the extent of the non-stationarity, and $\varepsilon_t \sim N(\mu, \sigma^2)$, $\{\varepsilon_t\}_{t=1,2,\ldots}$ i.i.d. A stationary demand series is obtained when $\alpha_n = 0$. Under certain conditions single exponential smoothing (SES) with smoothing parameter $\alpha_f = \alpha_n$ would the best method to forecast future demand. Assuming μ, σ and α_n unknown, simulation is used to study the effect of simple moving average (SMA) and SES estimates on the fill rate in a periodic review, order-up-to level control system in various scenarios.

The second model represents a way to generate demand that fluctuates more heavily and is based on random drawings from gamma distributions. The demand, $\{d_t\}_{t=1,2,\ldots}$, is generated as follows:

$$\mu_t = \mu_{t-1} \times n_t; \quad n_t \sim \Gamma(\nu_n^{-2}, \nu_n^2); \quad \theta_t = \mu_t \times \nu_d^2; \quad d_t \sim \Gamma(\kappa, \theta_t); \quad t = 1, 2, \ldots$$

Here $\mu_0 = \mu$, $\kappa = \nu_d^{-2} = (\sigma/\mu)^{-2}$, so the coefficient of variation of demand is constant, but the scale varies. The parameter $\nu_n > 0$ determines the extent of the non-stationarity and is

supposed to be small in order to prevent that the series $\{\mu_t\}$ approaches zero too fast. A stationary demand series is obtained when $\forall_t : n_t = 1$. Again, assuming μ, σ and ν_n unknown, simulation is used to study the effect of SMA and SES estimates on the fill rate in a periodic review, order-up-to level control system in various scenarios.

DEMAND CATEGORISATION IN A EUROPEAN SPARE PARTS LOGISTICS NETWORK

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Demand for spare parts arises whenever a component fails or requires replacement, and as such it is different from that associated with a 'typical' Stock Keeping Unit (SKU) (Fortuin and Martin, 1999). Managing spare parts is an important task in modern societies, with tremendous cost implications for the organizations that are holding relevant inventories. From a theoretical perspective, the intermittent nature of the underlying demand patterns creates significant difficulties as far as both forecasting and stock control are concerned. From a practitioner perspective, the considerable investments in spare parts availability signify that very small improvements in this area may lead to substantial cost savings.

An important operational issue involved in the management of spare parts is that of categorising the relevant SKUs in order to facilitate decision making, i.e. select appropriate forecasting and stock control methods, and enable managers to focus their attention on the most 'important' SKUs (however that is judged). This issue has been overlooked in the academic literature although it constitutes a significant opportunity for increasing spare parts availability and/or reducing inventory costs. In a recent investigation that deals with inventory control related issues for spare parts, Dekker and Bayindir (2004) noticed that despite the huge literature, developed since the 1970s, dealing with this problem, very few studies are actually considering solution implementation and with few exceptions (e.g. Botter and Fortuin, 2000; Boylan et al., 2008; Porras and Dekker, 2008) case studies are lacking.

In this paper, we explore demand classification and stock control related opportunities for increasing service levels and reducing costs in the spare parts industry. We analyse pertinent issues through a case study of a big Japanese electronics manufacturer. Our work has been launched along with the initiation of a project in the organisation under concern that aimed at restructuring their spare parts logistics network at the European level. The ultimate objective was to reduce lead-times and increase service availability as well as lower the overall stock levels in Europe. We will show through this case study, that although a rather 'basic' (as compared to recent theoretical advancements in this area) categorisation scheme and inventory control rules have been proposed, the organisational savings have been substantial.

Our work demonstrates the considerable scope that exists for improving relevant real word practices and allows insights to be gained into other pertinent managerial issues.

Keywords: *Spare Parts Management; Demand Categorisation; Forecasting; Stock Control; Case Study*

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THE NEW SALES FORECASTING METHOD FOR SHORT LIFE CYCLE PRODUCTS

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Managing supply chain for the short life cycle products – like fashion apparel, consumer electronics, personal computers, toys, books, CD's etc. – is a challenging experience for many companies. They try to ensure product availability and keep product obsolescence low. It is crucial to be able to respond to market signals as well as to develop accurate sales forecasts and update them based on recent information. [Fisher M., Raman A. (1999) Managing Short Life-Cycle Products, "Ascet Volume 1", no. 4/15] Thus, one of the most important things for these products is to find appropriate forecasting methodology, because the life cycles are too short (not longer than two years) for standard time-series forecasting methods. The standard forecasting methods require some historical data, which is often unavailable at the time when the forecasts are being performed. My method, described in this article, allows forecasters to use life cycle of similar products to arrive at the initial forecast.

When we introduce a new product to the market we can observe that a sum of sales quantity and the length of life cycle of these products resembles a sum of sales quantity and a length of life cycle of different products which were earlier introduced in the market. The sales volume of two products in the time displacement enables predicting sales by analogy. We have to have information about the minimum sales from the first of the two/three periods after launching the new product in the market place. Consequently, we can compare sales of this product with the sales of products which were earlier introduced to the market and calculate similarity in the shape and the sum of sales quantity. In order to achieve a more accurate similarity we can modify the sales series of products that has earlier been introduced to the market by using the following methods: calibrating and/or adjusting the length. Calibrating adjusts the sales quantity of compared product to the similar sum. Adjusting the length is matching time series in the aftermath of the time. We select the modified pattern which has superlative similarity to the sales of the new product and it becomes a forecast of the new product. It is profoundly important for the above referenced method to make forecast updates upon generating new information. We can repeat the entire procedure using the aforementioned method with the new expanded data.

The demonstrated method is not a master method but works well with products which life cycles are not longer than two years and allows deriving results with less than 1% error.

Keywords: *short life cycle, forecasting, similar products, measure of similarity, calibrating, adjusting the length*

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USING ADVANCE DEMAND INFORMATION AND EXPERT JUDGMENT IN STATISTICAL FORECASTING

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Practically all companies need to make forecasts in order to plan and manage their operations. This necessity is especially more critical in make-to-stock companies. While many uncertainties need to be forecasted for planning purposes, perhaps the most critical of all forecasts is the demand forecast. Failure to forecast demand, and in particular future demand trends in a reasonably accurate manner may be –and has been in many cases- lethal. In many business-to-business environments the demand exhibits high volatility and non-stationarity, not only because it is subject to seasonality and changing trends, but also because some individual client demands have significant influence on the total demand. In such an environment, traditional statistical forecasting methods may result in highly inaccurate forecasts, since they are mostly based on time-series analyses. That is, they assume that the forecast –hence the future- depends solely on present and past realizations, possibly added to a function of time such as linear trend. Nevertheless, it is impossible to predict shifts in future demand trends in this way. Therefore, many companies rely on judgmental forecasts rather than statistical forecasting methods. Specific customer information can only be collected and utilized by judgmental forecasts that are conducted by personnel that have in-depth information on individual customers, such as Area Sales Managers. The nature of the business-to-business environment makes it possible to collect –possibly imperfect– advance demand information (ADI) and develop expert opinion on some customers, e.g., because the customers have their own production plans that are known prior to the materialization of their orders, which is usually not the case in business-to-consumer environments. However, previous studies show that humans tend to exaggerate changes in patterns, causing large forecast errors. Therefore, judgmental forecasts should not automatically replace the statistical ones, and judgmental and statistical input should be integrated in such a way that the best use of imperfect ADI is made. Previous research also demonstrates that the current attempts for this integration have not been very successful. It is often the case that statistical forecasts are changed when they are highly reliable and ignored when they should be used to improve the judgmental forecast. How the integration of the judgmental and statistical input should best be made is the main research question that we address in this talk. In particular, we consider the demand forecasting problem of a make-to-stock system operating in a business-to-business environment where the signals of future demand are closely and dynamically followed, and we attempt to answer the following questions: 1. How can the judgmental updates be classified and best made use of? How can the bias of the forecasters be evaluated and countered accordingly? 2. How can the advance demand information be differentiated from judgmental updates and how can the best use of ADI be made? 3. What are the effects of the proposed methodology on the overall supply chain performance?

Keywords: *Advance Demand Information, Forecasting, Judgmental Updates*

DEMAND FORECASTING AND INVENTORY CONTROL FOR INTERMITTENT DEMAND

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I propose a new method for determining order-up-to levels for slow moving demand items in a periodic review system. Contrary to existing methods, it exploits the intermittent character of demand by modelling lead time demand as a compound Binomial process. Results from an extensive numerical study using Royal Air Force (RAF) data, show that the proposed method is much better at approximating target service levels and also improves inventory-service efficiency. Furthermore, the proposed method can be applied for both cost and service oriented systems, and is easy to implement.

A NEW BOOTSTRAPPING BASED METHOD FOR FORECASTING AND SAFETY STOCK DETERMINATION FOR MANAGING SERVICE PARTS INVENTORY

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In this paper, we address the problem of forecasting and managing inventory of service parts where the demand patterns are highly intermittent. Current methods first use Croston's correction or a variation to determine the average per period demand. The order quantity or order-up-to levels are then determined by calculating the safety stock required over the lead time. Currently, there are two approaches for determining the safety stock. Parametric approach assumes certain demand size and per period demand distribution and used this to derive the formula for the safety stock. Bootstrapping methods, on the other hand, generate a large number of data points for the lead time demand using simulation and use this to build the lead time demand distribution and then determine the safety stock. The best known bootstrapping based method for determining the safety stock is by Willermain et al. (2004). In their method, the periods with positive demands are generated using a two-state Markov model and the actual demand sizes using past demand history.

In this paper, we propose a new bootstrapping based method for calculating the safety stock. The key highlight our method is that instead of a two-state Markov method, the positive demand arrivals are generated using the historical distribution of the inter-demand intervals. We also perform a computational comparison of the proposed method with that by Willermain et al. (2004). Our computational results reveal that the proposed method generates lower average total cost without compromising service levels for both randomly generated intermitted demand data sets as well as for real demand data sets obtained from industry.

Keywords: *Intermittent demand, forecasting, safety stock, bootstrapping*

SERVICE CAPABILITY EVALUATION FOR LOGISTICS SERVICE PROVIDER BASED ON CUSTOMER VALUE CREATION

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Economic globalization has brought both opportunity and challenge to the logistics services providers in China, and it becomes indispensable for them to gain advantages to be more competitive by providing better performance in logistics service. As far as logistics service provider is concerned, service capability is one of the most important part of its core capability. The paper focuses on logistics service capability evaluation with the consideration that logistics service capability is customer-focus ed service value driven, and should be able to create, deploy and integrate available resources to satisfy the logistics needs in pursuit of better service performance. Logistics service provider capability can be considered as a multi-layered comprehensive concept. As to extrinsic performance, it is the competitiveness in market, which adds up the capability of properly utilizing internal and external resources, providing the right products and service to the customers and establishing competitive advantage in the competition with the rivals. It is affected by several factors potentially such as customer service, process of logistic operations, business system and financial situation, among which the customer service capability is one of the most valuable asset for the business because of a long-term benefit and an invisible intelligent salesman it could bring. Therefore most logistics service providers focus their attention on customer service capability, which contributes to their core competency. The competition between logistics service providers ostensibly presents in term of the service provided to its customer, but essentially is the ability to meet customers' demand, i.e., the ability to solve customers' problems and improve customers' satisfaction with a good reputation built up.

This paper defines the logistics service capability as the ability of logistics services providers to create and allocate resource in order to meet its customer's needs more and to achieve better service performance. Based on this concept a framework of the logistics service capability evaluation is structured taking dynamic factors into account and the capability evaluation index system for logistics service provider is provided. It reflects a comprehensive capability of the logistics service provider throughout the whole service process from receiving the orders to delivering products/services to the customers, which will affect the enterprises' competitiveness and ability to gain profit. The Principal Component Analysis method is employed in terms of multivariate statistical analysis and the synthesis evaluation.

According to the index system established above and the characters of the logistics services providers , choosing the index we should follow that: normalizing the data of indexes, writing out correlative matrix R of indexes, acquiring eigenfunction and the principal component, the determinant principle to determine the number of principal components , and integration of principal components. By structuring a database of service capacity evaluation index for ten logistics (storage) service providers in China together with the use of Factor Process of SPSS statistical analysis software the capability sequence of these the companies is illustrated and the analytic results are addressed.

Keywords: *Service Capability Evaluation, Logistics Services Provider, Customer value*

TWO-ECHELON SUPPLY CHAIN COORDINATION MECHANISM WITH PERISHABLE PRODUCTS UNDER FUZZY FORECAST

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In the field of inventory management, supply chain coordination mechanisms have been increasingly studied to design an effective scheme to reduce the inventory cost and optimize the overall system performance. However, most of the proposed methods assume that the key parameters of the model are either determinate numbers or a random variable with known distribution. In this paper, we try to relax this assumption and study the quantity discount coordination policy when the market demand is uncertain, and could be forecasted as different fuzzy variables by the supplier and the buyer.

In reality, it is difficult for companies to achieve the exact value of the decision variables such as market demand. Moreover, they may even not have sufficient historical data to extract the exact distribution of the variable. Recent researches show that fuzzy theory is useful in analyzing problems involving such uncertain or imprecise variables. Therefore, we introduce fuzzy variables as uncertain forecast parameters in this paper to represent the market demand for both parties.

Furthermore, we extend our research to an even complicated yet practical situation by introducing the concept of perishable products to the coordination mechanism. Although there are extensive literatures concerning the decaying nature of the products, most of them mainly focus on the independent inventory strategy inside companies. Those problems involving coordination between supply chain members of perishable products have not been adequately addressed yet. Based on all these considerations, we organize the paper in the following three aspects: Firstly we formulate the mathematical programming for fuzzy-based supply chain management with perishable products under two circumstances: without and with quantity discount coordination. Two assumptions are made: (i) The market demand is a fuzzy variable for both parties, and the buyer enjoys more accurate forecast of the fuzzy demand than the supplier; and (ii) The inventory level of the perishable products satisfies a negative exponential function. Secondly, in order to simplify the calculation, we set these two demand forecasting fuzzy numbers as normal triangular variables, and perform fuzzy arithmetic referring to function principle and credibility theory to deal with the objective function and constraints in fuzzy sense. The optimal quantity discount policy is then derived. Finally, based on the model and its solutions, numerical and sensitivity analysis are presented in the conclusion section. The influence of the fuzzy demand forecast accuracy of both parties to the whole supply chain performance and to the profit share is discussed; the relationship between the decaying rate of the product and the inventory management policy is revealed; and the effect of the quantity discount mechanism is also illustrated. All in all, this paper highlights the fuzzy theory as a proper method for demand forecasting, and proof the effectiveness of its combination with coordination mechanism in supply chain management.

Keywords: *inventory management; fuzzy forecast; coordination mechanism; perishable products*

THE BULLWHIP EFFECT: AN EMPIRICAL ANALYSIS

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The bullwhip effect is a very classic topic in operations literature (e.g., Lee et al. 1997a) and recent papers investigate it through both theoretical models (e.g., Lee et al., 1997b) and simulations (Croson and Donohue, 2003) .

Literature suggests several effects (extra cost of inventories, extra capacity requirements and extra stock out costs) and several causes (lot sizing rules, extrapolative forecasting processes, pricing policies, rationing games etc…) and fixes (information sharing, VMI, no quantity discounts etc..) (Mason-Jones and Towill, 2000).

In our paper we investigate the bullwhip effect through real life data from a large multi-national company in the hair-care industry. We collected data on hundreds products for a whole year (for some 10 brands) at the week level.

We measure demand over time for these products both at a retail chain (sell-out) and at the manufacturing company supplying the retail chain (sell-in).

These data at the two stages of the supply chain enable us to investigate several issues and, possibly, answer a few relevant research questions:

1. First we aim to measure the extent to which the bullwhip effect impacts a real life supply chain, thus to provide evidence regarding the real extent of this phenomenon.
2. On a second perspective, we aim to analyze the contingent factors that influence demand variability along the described supply chain. Managers from the company report a large increase in sell-in during the fourth week of the month not reflected in the sell-out data. We investigate the issue and try to explain such fluctuations in the light of the incentive schemes of the sales-force. Our hypothesis is that salespersons tend to push sales toward the end of the one-month-long canvass period (through price reductions). Thus our analyses suggest a potentially a new source of demand fluctuation in the supply chain that is mentioned in very classic cases (e.g., Barilla case) but has not been investigated scientifically yet.
3. Also, we take into consideration differences across products, in order to identify what product characteristics may enhance or reduce the bullwhip effect. Our hypothesis is that products with a stable (sell-out) demand are the ones the retailers are willing to forward-buy. So in a way either sell-out is variable (and thus sell-in is variable) or it is stable but this paves the way to forward-buy to take advantage of the odd incentives of the manufacturer's sales-force.
4. Finally, we seek to analyze the differences in terms of variability in two different channels (supermarkets and drugstores). The hypothesis is that in large and centralized chains (i.e., supermarkets) the ability of the manufacturer's sales-force to drive demand is rather limited (since it is mostly driven by automatic replenishment programs) while in the case of smaller and more decentralized chains (i.e., drugstores) the manufacturer's sales-force has more latitude on the retailer buying behavior.

The paper thus contributes to current literature since it provides empirical evidence of a debated issue and highlights future research needs both in terms of contingent factors to which literature has devoted only partial attention and in terms of managerial actions to cope with the effects of these fluctuations.

Keywords: *bullwhip effect, contingency factors, supply chain structure*

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IN ABSENTIA

RETAILER OPTIMAL POLICIES IN A BICRITERIA OBJECTIVE WITHIN A PRICE-DEPENDENT NEWSVENDOR FRAMEWORK

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1. Introduction: One of the most recent extensions of the classical newsvendor problem (NVP) is the formulation of a bicriteria decision problem whereby the newsvendor incorporates into the same objective function the conflicting goals of maximizing the expected profit and the probability of exceeding it, the latter known also as the satisfying objective. Parlar and Weng (2003) review the literature on the use of the two objectives within the NVP framework and present the pioneering work on the subject. Another promising research area in NVP framework is to model both the price and order quantity in the retailer's optimization policy, along the lines of Arcelus et al (2005a) and Petruzzi and Dada (1999). This paper merges these two extension areas. Its purpose is to address the bicriteria decision problem whereby the retailer incorporates in its objective function the conflicting goals of maximizing the expected profit and the probability of exceeding it through the determination of both the optimal price and the order quantity within a newsvendor framework.

The paper is organized as follows. Section 2 describes the single criteria optimal expected profit and the probability of exceeding it. Both are input to the bicriteria model. However, Arcelus et al. (2005b) has discussed that there exists a relationship between the price and the probability of exceeding expected profit and hence the unconstrained single criteria objective of maximizing the probability of exceeding the expected profit does not make sense in a price-dependent newsvendor problem. We have overcome this problem through two different assumptions. The first considers the optimal probability to be 1 as it acts as the upper bound on the probability, determine optimal probability with a valid range of price i.e. retail price should be greater (less) than procurement cost (when demand function value is zero). The second Section 3 highlights numerically the main features of the model, with linear/iso-elastic demand functions and additive/multiplicative error structures considered while illustrating the managerial insights. The Optimization Toolbox of MATLAB (2006) is the primary computational tool for these purposes. A Conclusions section completes the paper.

2. The bicriteria model: This section summarizes the main features of the bicriteria model. The starting point is a retailer.

Keywords: *Newsvendor problem, Price-dependent demand, Degree of risk behaviour, Alternate optimization objectives*

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A CONTINUOUS REVIEW INVENTORY CONTROL POLICY WITH ORDER SPLITTING AND EXPEDITING

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Expedited shipments are often seen in practice. When the inventory level of an item gets dangerously low after an order has been placed, material managers are often willing to expedite the order at extra fixed and/or variable costs. By employing a fast transportation mode (e.g., by air), the buyer can have an outstanding order arrive earlier than planned. In this paper, we propose a single-item continuous review inventory policy with order splitting and expediting, which can be considered as an extension of ordinary (*s*, *Q*) models. Besides the two usual operational parameters: reorder point *s* and order quantity *Q*, it consists of a third parameter called the expedite-up-to level *R*. If inventory falls below *R* at the end of the manufacturing lead-time, the buyer can request the supplier to deliver part of an outstanding order via a fast transportation mode. The amount expedited will raise inventory to *R*, while the remaining order is delivered via a slow (regular) transportation mode. Consequently, an outstanding order is split into two deliveries.

The proposed policy minimizes the expected total cost per unit time, subject to a service level constraint. Both the no-shortage probability and fill rate service measures are employed in this paper. Simple procedures are developed to obtain operational parameters. Computational results show that the proposed policy can save large costs for a firm, especially if service level is high, the extra cost for expediting is small, or the manufacturing lead-time is long.

INTEGRATED ICT SYSTEM FOR LOGISTICS: THE CASE OF THE ITALIAN REGION FRIULI VENEZIA GIULIA

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The European Commission in 2001 stated in the White Paper "European Transport Policy for 2010: Time to Decide" [1], that the answer of the Community to the increasing demand for transport cannot be just to build new infrastructures but that the transport needs to be optimised to make it more sustainable. Then, it is of fundamental importance to increase the usage of intermodal transport. The information is essential for the management of an intermodal chain and then, to have an efficient transport, it is necessary that the information flow runs in parallel with the physical transport. Several European projects started on ICT in intermodal transport chain (see, e.g., INFOLOG [2] and the subsequent projects reported in [3]) but, as stated by the European Commission in the mid-time review "Keep Europe moving: Sustainable mobility for our continent" [4], the problem of sharing information is still an issue. We think that some reasons are that the projects suffer from gigantism and that sometimes they meet the scepticism of some operators in the transport chain.

In 2006 a new European project, FREIGHTWISE: Management Framework for Intelligent Intermodal Transport, started and still ongoing until 2010, aims to provide a reference architecture, using also results from other projects, that can support the information flow in the transport chain [5]. Another European project, EURIDICE: European Inter-Disciplinary Research on Intelligent Cargo for Efficient, Safe and Environment-friendly Logistics, started in 2008, aims to create the necessary concepts, technological solutions and business models to establish the most advanced information services for freight transportation in Europe [6].

In our work we describe a particular project that want to start to implement an ICT system in an Italian region, Friuli Venezia Giulia, belonging to the Adriatic sea region, that is small but it has some special characteristics as a border with two countries, three ports, an airport and the presence of mountains, plain and coast that can made it attractive to implement a case study.

The project, as the other ones, starts with an analysis of the requests from the operators and a comparison with other similar projects. We found that even if the actors show interest, their requirements are often minimal and that they are unwilling to share information even with their customers. There is then an asymmetric information problem due to the dominant position of some operators.

From the requirements of the operators we found that they are more interested in four topics: acquiring real time information from the infrastructures, managing hazmat material,

introducing use of electronic documents and sharing information on tracking and tracing between operators. The project develops implementing these four packages of the framework. In this way, one tries to create some quick wins that can generate a knock-on effect to attract new operators and then more specific packages could be added. We think that a bottom-up approach can obtain more results than a complex framework approach because it can start with some small packages that can meet the real requests of the operators.

Based on the above remarks, the final paper will focus on a general model developed to formalize the proposed approach and on the analysis of the interviews that will validate the model and the four packages of the framework. It will be also described a specific project on ICT for the terminal container of the Port of Trieste that uses the same methodological approach. The port of Trieste is a possible node of the general framework and the two projects have in common the purpose of increasing the communication among the operators. Then the two systems are complementary and in the paper it will be analysed the vertical integration and the connections between the two projects.

Keywords: *interaction infrastructure, freight transport, case study, bottom-up approach*

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UNDERSTANDING INVENTORY MANAGEMENT SYSTEMS IN HEALTH SERVICES: RESULTS OF AN EXPLORATORY CASE STUDY

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Since the nineties, the health care sector has changed rapidly. Due to increased competition, a growing influence of patients and a stronger necessity to deliver health services in an efficient and effective way, many health care organisations have started projects in the area of service quality, clinical pathways, information systems and patient logistics (e.g. Stock et al. 2007; Mahmoud and Rice, 1998). Clearly, not only in practice but also from a theoretical point of view the area of health care management has changed significantly. During the past fifteen years an impressive number of studies performed in disciplines like Economics, Business Logistics, Operational Research and Business Administration have enlarged our knowledge regarding the health care sector considerably (e.g. Li et al., 1996; Jarett, 1998; McFadden, et al., 2004; Ruiz, 2004). Moreover, many models, applications and approaches originally developed for manufacturing environments are nowadays transferred into the area health services amongst which productivity analysis, financial management, strategic management and operations analysis.

Despite the fact that Hospitals carry large amounts of a great variety of items, health care organisations have paid little attention to the management of inventories (Nicholson et al., 2004). Studies performed in the past as well as more recent research suggest that inventory costs in the health care sector are substantial and are estimated to be between 10% and 18% of net revenues (e.g. Jarett, 1998). At the same time, hospitals are forced to increase their internal service performance and it is also for this reason why a strong focus on inventory management has become paramount in many hospitals nowadays. It will be of no surprise therefore that many hospitals have started with projects in the area of inventory management in order to reduce costs and improve service levels.

Despite the impressive body of knowledge regarding inventory management in an industrial setting, some gaps and holes exist in our knowledge with respect to inventory management in a health service setting. Clearly, a number of problems show up when directly transferring the techniques and approaches developed in industry to the management of inventories in hospitals. In a hospital, patient caregivers in many cases must be sure that particular products like drugs, are always available. Additionally, in many hospitals it is not always clear what party is responsible for the money tied up in inventories. Moreover, decision-making processes in the area of inventory management within hospitals apparently are often heavily influenced by the many stakeholders involved. Some studies suggest that setting par levels for items in a healthcare setting often tend to reflect the desired inventory levels of the patient caregivers and often seem to be more politically and experienced-based driven rather than data-driven (Nicholson et al, 2004). Finally, inventory management projects in hospitals are often strongly linked to automation and to projects in the area of information, patient logistics and supply chains policies. Manual dispensing of medications in hospitals in Canada, the United States and Europe for instance, is more and more replaced by automated

medication distribution systems in order to help with distribution of medications to patient care areas and to improve inventory control (e.g. Novek, 2000).

Despite some rather unique characteristics only few studies have addressed the question how the design and implementation of inventory systems in a health service setting takes place. Moreover, only a limited number of empirical studies are available regarding the question how conflicting interests, power relationships of stakeholders, as well as the complexity of hospital supply chains influence the shaping and implementation of inventory systems in hospitals. Clearly, many different stakeholders are involved in the (re)shaping of inventory systems in hospitals and together with the diverse and unique characteristics of a great variety of hospital products, projects in the area of inventory management are far from a simple, straightforward design process. Undoubtedly, having a clear understanding of how inventory systems are affected by the specific characteristics of health services can be helpful to strategic and tactical decision-making processes on inventory systems. Additionally, this understanding can also be beneficial for the effectiveness of inventory projects.

Our full paper draws heavily on an exploratory case study performed during the period 2007-2008. The case study aimed at providing an in-depth understanding of the critical factors that influence the design and functioning of inventory management systems in hospitals. Additionally, four mini cases were conducted aimed at making repeated observations. In doing so, a socio-technical approach was taken as a starting point. As stated above, projects in the area of inventory management in hospitals are often complex of nature and are often aiming to be both technologically and organisationally innovative. For this reason, these projects often involve a large number of different professions and therefore include not only technical but organisational aspects as well. Establishing the best fit between the technical system (e.g. the technical features of the inventory system) and the social system (e.g. social practices and attitudes towards the inventory system) is recognized as being one of the main challenges that organizations are confronted with when applying a socio-technical approach (e.g. Klecun and Cornford, 2005).

In our full paper, first the results of a literature study are presented leading to an exploratory framework that guided the empirical part of our research. In the second part of our paper, case data is further analysed. In doing so, we concentrate on identifying critical factors from three perspectives. First of all, the influence of organisational arrangements in terms of the allocation of authorities and responsibilities are further elaborated on. Secondly, the inventory management system is analysed from an information system perspective. Finally, the professions affecting the performance of the inventory management system are described and analysed. In doing so, we concentrate on the specific situation, hospitals find themselves in. In the last section of the paper the findings of the case studies are presented. In doing so, two perspectives are taken. First of all some tentative conclusions are drawn about how the specific characteristics of a hospital setting might influence the shaping and performance of an inventory system in a health service setting. Secondly, conclusions are derived about the application and usefulness of the exploratory framework.

Keywords: *Inventory system, exploratory case study, health services*

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KANBAN SYSTEMS. KEY COMPONENT OF INVENTORY CONTROL

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What is the Kanban? The word Kan means "card" in Japanese and the word "ban" means "signal". So Kanban refers to "signal cards".

The concept of time-based management is nothing new for managers outside of Japan and has been in practice for many years. However, the Kanban process involves more than just in time deliveries and inventory control. Briggs notes that the Kanban process components are the most exportable of Japanese techniques, but the complete process itself has not yet been successfully adopted outside Japan.

A system of continuous supply of components, parts and supplies, such that workers have what they need, where they need it, when they need it. The Kanban is a concept related to lean and just-in-time (JIT) production and distribution. The Kanban scheduling systems are among the most simple, effective and inexpensive means for manufacturing production and inventory control.

The Kanban production control is simple yet subtle; empowering and also threatening; robust yet delicate; both adaptable and rigid; easy to explain but difficult to understand. It is a key component of most Lean Manufacturing strategies.

This paper describe the Kanban systems and explain where to use them. They show how to design systems, how to choose the number of cards, and describe two real-life examples. This paper presents the case study. The first case study presents the implementation concept in production. The second case study is report in implementation the Kanban in distribution.

The Kanban systems provides accurate and real knowledge on the operating efficiency. An increase of this rate brings huge financial profits, which is shown in the following example.

AN EMPIRICAL ANALYSIS OF INVENTORY PRODUCTIVITY IN GREEK RETAIL SECTOR: 2000-2005

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Inventories have generally been the most difficult asset to be managed both for merchandising and manufacturing firms. Managers face such difficulties because the acquisition, finance and selling procedure of inventories bear with goals which are mutually exclusive; e.g. the effort to minimize the inventory level is contradictious to the goal of minimizing the probability of inventory shortage. On the one hand, inventory management deals with specifying, retaining and controlling the desirable inventory level and on the other hand with minimizing total inventory cost. In other words the problem of managing inventories is an optimization problem which lies between overstocking and under-stocking cost. Shortage of inventory implies unsatisfied demand and sales shrinkage. Excessive inventories include the cost of providing the physical space to store the items, taxes and insurance, breakage, spoilage, deterioration and obsolescence and the opportunity cost of alternative capital investment as well.

Moreover, in all firms, except those belonging to the financial and service sector, inventories represent a large proportion of current and total assets. For example, Gaur et al. (2005)[1] report that in US retailing during the year 2003, inventories represent, on average, 36% of total assets and 53% of current assets. Likewise, our dataset on Greek retailers, during the period 2000-2005, show that inventories represent on average 38% of total assets and 51% of current assets. Generally, as it stems from the relative literature, investment in inventory represents a significant amount of the total funds available in firms. For these reasons inventory management receives great attention from market analysts, bankers and investors.

A financial index that combines the cost of goods sold with inventories is the inventory turnover ratio, which is the ratio of a firm's cost of goods sold to its inventory level. This index shows how many times inventories are turned over during the accounting year. That is, inventory turnover ratio expresses the ratio of inventory productivity. Hence, inventory turnover ratio can often be used as a comparative measure of inventory productivity between firms, or in evaluating the effectiveness of inventory management.

We have used dataset obtained from Greek Retailers for the period 2000-2005. Our dataset consists of repeated observations on the same cross section of firms over time drawn from financial data of their annual income statements and annual balance sheets. We have further extended the analysis by looking at the sales growth process in association with the inventory turnover ratio.

In this study we investigate the determinants of inventory productivity. The study is based on an econometric analysis of inventory behavior using an inventory turnover model. The empirical implication of the model was conducted on a sample of financial data for 566 Greek Retail firms for the years 2000-2005. By employing panel data techniques it was found that inventory turnover ratio is negatively correlated with gross margin and positively

correlated with capital intensity and a measure of sales surprise. Moreover, the inventory turnover reaction to sales changes was also studied when firms operate in "sales-declined region" as well as in "sales-increased region". It was found that changes in sales ratio bring on bigger changes in the latter case than in the former one. We find that, a 1% increase in sales growth ratio is associated with a 0.46% increase in inventory turnover in the former case, and only 0.26% increase in inventory turnover in the latter case. In addition, we estimated the inventory turnover trend over the entire period examined and we found that it varies across firms.

Our results are useful in operation and financial management, helping managers make aggregate-level inventory decisions as well as identify the causes of differences in inventory turn between firms and overtime. It should be noted that the present study is the first empirical work on inventory behavior in Greek literature and the results coming from it can stimulate future research into possible ways of effective inventory management.

Keywords: *inventory turnover, product variety, sales growth, panel data analysis, fixed effects*

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IMPROVING SUPPLIER-BUYER COOPERATION WITH CREDIT PERIOD INCENTIVES UNDER ASYMMETIC INFORMATION

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Harmonious cooperation and close coordination play an important role in the efficient supply chain management. However, it is a difficult task to settle a collaborative arrangement between the supply chain members since they may be tempted to deviate from any agreement in order to maximize their own profits if they belong to separate entities with different interests. Therefore, some incentive mechanisms to coordinate decisions are necessitated to enforce coordination between the supply chain members.

Although there exists an extensive literature concerning the effects of trade credit on the optimal inventory, most of the studies in this area deal with the problem of determining the buyer's optimal ordering quantity and reorder level that will maximize the buyer's or the vendor's total profit per unit time under the condition of permissible delay in payments. However, the credit period as an effective coordination mechanism for the buyer-vendor coordination has not been adequately addressed yet.

This paper examines credit period incentives for efficient inventory management. A buyer-vendor supply chain for a single product is considered and a model to study the benefit of coordinating supply chain inventories with credit period under asymmetric information is proposed. A supplier requests a dominant buyer to alter his current selling price and order size such that the supplier can increase his own profit. To entice the buyer to accept this request, the supplier compensates the buyer for the buyer's decreased profit, and possibly provides an additional saving by offering the reseller an order-size-dependent credit period such that the buyer is dispensed with interest on the money payable during the credit period. However, that the supplier has full information about the buyer's cost of capital rarely will be true in pratice. In this paper we drop that full information about cost of capital cost. Our analysis sheds managerial insights into the role and limitation of quantity discount strategy by comparing it with the credit period strategy and reveals that which is better strategy relies on both the supplier's cost of capital and the buyer's private information about his own cost of capital. Therefore, quantity discounts as coordination mechanism alone are not sufficient to guarantee joint profit maximization, which is interrelated with buyer cost of capital and suppler's. The proposed model serves as a pioneering work on investigating the effects of cooperation with credit period incentive integrated in the inventory system.

Keywords: *inventory management; credit period incentive; asymmetic information*

AN ALTERNATIVE FORECASTING METHOD FOR TIME SERIES WITH LINEAR TREND AND MULTIPLICATIVE SEASONALITY

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It is common to find time series data with linear trend and multiplicative seasonality. If it can be assume that the observations "oscillates" around a straight line then it is said that the time series exhibits linear trend. Multiplicative seasonality means that the data is influenced by the seasons of the year and this influence increases through the time. Fortunately, there are two classical and widely used options to forecast this kind of data.

The first approach is to apply a logarithmic transformation to the observations in order to change the multiplicative seasonality for an additive seasonality. The next step is to fit an ARIMA model to the transformed data. The ARIMA models have been widely used in the literature and they have strong statistical bases as the biggest of its advantages. A wide range of data can be fitted with ARIMA models including those with additive seasonality. The main disadvantage of this approach is that it works with a transformed time series instead of the original one and therefore, the validity of the approach can be questionable. An other disadvantage are the prediction intervals that can be to wide for the real data.

The second option is the multiplicative Holt-Winters method. This method belongs to the exponential smoothing methods, characterized by giving exponentially greater weights to recent observations. An important advantage of the multiplicative Holt-Winters method is that it can be apply directly to the original data without logarithmic transformations. However, the assumptions of the statistical bases of the method may be not realistic, specially the assumption of perfect information. In addition, the parameters of the method need an optimization algorithm like the generalized reduced gradient to be estimated and the accuracy of this algorithm depends on the election of the initial values, which need another heuristic algorithm to be estimated.

The disadvantages of the options mentioned before makes desirable the existence of a method able to forecast the original data directly while its statistical bases keep strong and its parameters can be estimated without necessity of complex optimizations algorithms.

In this work an alternative method, able to catch linear trend and multiplicative seasonality and with the desired advantages is proposed. In addition, the alternative method uses less parameters than the others.

This is an advantage when parameter penalization criteria as AIC and BIC are used in order to compare different forecasting methods. Real time series data will be used to compare the performance of the three options.

AN EXTENDED NEWSVENDOR MODEL TO INCORPORATE RISK ATTITUDES OF DECISION MAKER

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One of the most important models in stochastic inventory theory is the newsvendor model. In the standard newsvendor models, the objective of the newsvendor model is to seek for an optimal order quantity which balances the loss of ordering too many against the forgone profit of ordering too few. It is usually assuming the decision maker is of risk-neutrality and expected total-cost approach is commonly applied. Classical newsvendor model enjoys a simple structure and has been applying to wide array of business areas including retailing, manufacturing and production, air-tickets and hotel-room reservations, and etc.

However, in practice, there are evidences of counter examples indicating decision makers do have a risk preference other than risk-neutral. They do not consider the expected cost-minimizing (or profit-maximizing) order quantities. In recent literatures, some researches have been conducted to involve decision makers risk attitudes. Most of these researches are considering the risk-averse decision making. In our opinion, the previous studies only partial solved the stochastic inventory management with risk preferences. A general model with consideration of risk preferences should be flexible to cover the whole spectrum of risk attitudes from risk-sensitive to risk-numb. In this paper, we attempt to propose a new extension of standard newsvendor model with an incorporation of risk preferences of all types. In addition, we would like to have the extension on the success ground of the standard newsvendor model. With a minor modification to the standard model, the newly proposed model can be widely adopted by industrial participants with little migration effort.

We would like to highlight that in stochastic inventory decision, decision maker has to evaluate both the cost amounts and corresponding occurrence probabilities. Decision makers may have other risk preferences than risk-neutral. Some of the decision-makers maybe risk-sensitive and some of the decision-makers maybe risk-insensitive. The risk-sensitive decision makers we are referring to those worry much more about the occurrence probabilities than the cost amounts. They worry about a scenario likely to occur even if the associated cost maybe relatively low. They would like to have the decision bias to the scenario of the highest probability of occurrence. On the other side, there maybe some decision makers who are risk-numb. They worry much more on the cost amounts than the corresponding occurrence probabilities. They would like to have a decision minimizing the total cost regardless how likely/unlikely scenarios occur. The classical newsvendor model takes no subjective concerns into consideration due to the risk-neutrality assumption. The objective probabilities are directly employed as the weights to compute the expected total cost. When modeling the subjective risk attitude to the stochastic inventory decision, we suggest constructing a new set of weights. In our paper, we proposed a mechanism which modifies the objective probability to incorporate the subjective risk attitude. We simply call modified probabilities as subjective probabilities. In light of the newly constructed subjective probabilities, we applied expected value approach to derive risk-sensitive and risk-insensitive order quantities in stochastic inventory management.

Keywords: *newsvendor model, stochastic inventory management, risk modeling*

PROVIDING CUSTOMER FLEXIBILITY THROUGH SERVICE INNOVATION: AN OPTION-BASED PRICING STRATEGY

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Competing for customers and market share has become increasingly challenging for service organizations. The intangible nature of service products makes them difficult to patent and thus easy to copy (Oke 2004). As such, service organizations have to depend on differentiated services (that are less visible to competitors and less easy to copy) as opposed to products to remain competitive and gain market share. In this paper we focus on option-based innovative pricing strategies that can be offered to customers by service firms. We explore how such strategies might give customers increased flexibility and other benefits over and above competing pricing strategies offered for similar service products.

Attracting and gaining customer loyalty through different pricing strategies has been extensively studied in the literature (So, 2000; Armony and Haviv, 2003; Afeche and Mendelson, 2004; Kittsteiner and Moldovanu, 2005). Pricing strategies in a service system can be used to increase revenue for the service provider by taking advantage of differences in customer preferences. Price differentiation is used in many service settings including call centers, transportation or communication systems, the internet, etc., that offer various modes of service at different prices. In such systems differentiation is achieved through different priority levels offered to different customers. Other service systems including airport check-in operations offer priority services to higher fee paying customers. However, such systems offer limited flexibility to customers in terms of the options available to customers and are therefore not as competitive as they can be. For example, a customer that secures a VIP-type pass that always allows priority access to a server upon arrival may not benefit from the service when there are no queues in the system.

In this paper we explore an innovative competitive pricing strategy for service systems that allows for service differentiation, while giving customers the flexibility of exercising an option to skip the waiting line, based on their observed/perceived level of system congestion whenever that level is beyond their current capacity to wait). Although we see examples of such systems being used in service systems such as the "*Front of Line Pass*", at Universal Studios, and "*FlyClear*", at certain U.S. airports, to our knowledge there is a dearth of studies that explore the viability of such innovative pricing strategies. Thus our aim in this study is to consider different service systems and carry out a conceptual and theoretical analysis to investigate and compare this innovative pricing strategy with the traditional service pricing/differentiation approach in order to determine which pricing strategy is more beneficial to the provider by being able to offer competitive pricing and secure more profitability whilst at the same time offering more flexibility and other benefits to customers.

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THE OPTIMISATION OF INVENTORY IN THE SUPPLY CHAIN BY APPLICATIONS OF THE HYBRID'S STRUCTURE BASED ON OF JUST IN TIME, QUICK RESPONSE AND VENDOR MANAGEMENT INVENTORY SYSTEMS

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The implementation of the supply chain management strategy introduces essential changes into the functioning of a manufacturing enterprise within the created supply chain.

Such a system introduces certain specific requirements for the other chain links which want to be a part of it. What is more, the implementation of this idea changes the nature of connections and mutual relations between the participants of the supply chain which are based on partnership.

Main reasons of the changes are: decrease of inventory size and reduction of the delivery cycle, but with simultaneous increase of customer's handling level.

Further applications of the hybrid's structure based on a Just in Time, Quick Response and Vendor Management Inventory has a specific of influence on decrease of inventory size in the supply chain.

The article presents the range of changes and the arrangement of mutual relations between all links of the supply chain and hybrid's system based on Just in Time, Quick Response and Vendor Management Inventory.

Keywords: *Supply Chain Management, optimisation of inventory, Just in Time, Quick Response, Vendor Management Inventory*

STOCK DECREASING PROCESS AND PROJECT VIEW OF PRODUCT MANAGEMENT

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Since 1999, we have been continuously involved in several research projects focused on company production and procurement management with regard to company competitiveness, restructuring spinal intra-company relations in small and medium-sized businesses leading towards application of decisive market competences. The research work, inter alia, confirms a significant conclusion relating to stock optimisation in all links of the value-generating chain, i.e. implementation of product management project view. Value-generating process management requires a behaviour based on a unifying marketing management concept, application of product management principle, integrated planning and management, all-inclusive standardisation and application of process management in such a way that individual conflicts and clashes between participants can be eliminated to the benefit of the entire production, procurement, and sales management development. Key roles are assumed here by

- internal supply chain and
- external supply chain.

What justifies the necessity of dealing with the value-generating chain as a managed project? It is namely the following:

- possibility of improving on individual operations within the chain,
- solution of the co-operative production increase problem (outsourcing),
- increasing handling and transportation costs,
- competitive pressure,
- growing globalisation,
- e-commerce importance strengthening,
- building on contractor relations and increasing their comprehensive nature,
- necessity of decreasing stock.

Pull strategy application gives the internal/external chain overall concept a new sense. This principle expresses the fact that both within the company value-generating chain (internal supply chain), and within the entire supply chain (external supply chain), the entire product creation project implementation process is always „carried on“ by that level (implementation) of the chain, which is closer to the customer. No intra-company activity should take place and no participant in the supplier-customer chain should make any action upstream the value-generating chain than as requested by customers (internal or external) downstream. That means that all activities are designed to customer wishes (including individual participants in the chain acting in the role of customers here) and thus it is the customers who carry on the implementation process.

Another important aspect is the fact that on the other hand, it is possible to see certain regularity in the entire chain when a new downstream effect originates in the chain. It reveals the fact that innovation cycles spread in the value-generating chain as an avalanche the more so the farther downstream the source of technology for use with end consumers is found. Whereas for example innovation in electronic parts industry production facility manufacturer takes approximately five years, in manufacturers of those parts it takes approximately half the time. With computer producers, the innovation cycle then reduces to a matter of months. Eventually, in the sphere of applications, this could be weeks. This regularity obviously applies to other spheres too.

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