Book of Abstracts

19th International Symposium on Inventories

August 22-26, 2016
Budapest, Hungary

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ISBN 978-615-5270-25-3

Editor-in-chief: Attila Chikán
Technical editor: Zsuzsanna Heiszler (Diamond Congress Ltd.)

The professional and grammatical level of the materials is the authors' responsibility.

Printed in Hungary - 2016
OOK-Press Ltd., Veszprém, Hungary
Responsible for printing: Attila Szathmáry

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Plenary Lectures

Some New Avenues for Spare Parts Demand Forecasting

Rommert Dekker

Erasmus University Rotterdam, Rotterdam, The Netherlands

Forecasting demand is an important phase in spare parts management, yet it is quite more difficult than forecasting demand for new products. Industrial research shows that there are quite some parts with very low, intermittent or erratic demand, which makes the forecasting difficult. In practice this may mean that for some parts there are not enough stocks, while there may be overstocks for more than 50% of the parts. Moreover, quite often large number of parts need to be scrapped as there is no more demand for them. Boylan and Syntetos (2009) present an overview of forecasting methods primarily based on historical data on past demands. In this presentation we will present some new ideas which combine demand data with information from other sources. Apart from presenting the ideas we also indicate how they can be combined with inventory control policies.

The first idea is based on installed-base data. Some companies, like airplane manufacturers keep quite specific information on the planes they made in the past and use that data to relate the spare parts demand to it. Combining this data with preventive maintenance schemes allows one to predict the parts demand for preventive maintenance even in case the actual use per execution is stochastic. We will present some empirical results on this method, which can also be applied for estimating parts needed in repairs.

A related idea is based on information on service contracts between manufacturers and equipment users. Although the idea is quite simple as well as the resulting inventory control, the calculations to determine optimal policies are quite complex.

A second idea is based on condition monitoring methods, producing indications when spare parts may be needed. Although such methods may also produce false alarms they do allow a better inventory control than one which is only based on historical data.

In the consumer product sector companies have much less information about their installed base, as they are not informed on when customers discard their products. For this environment we developed methods based on economic considerations to forecast the evolution of the installed base and show with empirical data the value of the approach.

The final idea is not based on installed base data, but uses extreme value theory to improve the tail of empirical demand distributions. We present some tests of this method based on artificial and on real data.

Overview of ISIR Special Issues – Key Topics Identified by Text Mining

Krisztina Demeter, Andrea Kő

Corvinus University of Budapest, Budapest, Hungary

Time to time it is important to make a meta-analysis on ourselves: what is our heritage, where are we now and where do we (possibly) go? The purpose of our paper is to make an experiment using a new method to highlight the history of ISIR Symposia. The paper tackles the following research questions:

RQ1: Can we make a map of the most frequently used issues of the conference?

RQ2: How these research issues can be categorized and evolved over time?

The paper relies on the 11 special issues of ISIR published in International Journal of Production Economics since 1994 covering more than 500 papers. In analysis strategy we apply content analysis by text mining full articles. We follow the "bag of words" approach in document representation; the "bag" of its words characterize the content disregarding grammar, but keeping multiplicity. It operates by identifying repeating themes and categorizing them. In general, categories can be built up from the data or come from some external source (for example from a taxonomy). We will follow the first option in categorization. To produce "bag of words" we build a text preprocessing model. Finally, we analyse the output, group them to a classification scheme to build a model of the ISIR research issues.

Keywords: *overview, inventory research, text mining, ISIR*

Replenishment and Ordering Decisions for Fresh Produce with Backroom Effect

Lin Li[1], **Ou Tang[2]**

[1] *School of Business, East China University of Science and Technology, Shanghai, China*

[2] *Division of Production Economics, Department of Management and Engineering, Linköping University, Linköping, Sweden*

Backroom effect, not only refers to the role of backroom as a reliable source to replenish the shelf-displayed goods, but also indicates its superior preserving condition to reduce the deterioration and maintain the freshness of fresh produce. This paper studies the influence of backroom effect on shelf replenishment and ordering decisions for fresh produce, in which the deterioration rate in backroom is lower than that on shelf, and newly replenished products are more likely to be purchased by consumers, i.e. consumption has a Last-in-first-out (LIFO) assumption. Considering the "replenish-point, replenish-up-to-level" (r, S) shelf replenishment policy, we formulate the perceived freshness to describe real-time average freshness of facings on the shelf. With the assumption of perceived-freshness-and-shelf -level dependent demand, we develop a decision-making model determining the ordering quantity and shelf replenishment point. Furthermore, by applying Generalized Reduced Gradient (GRG) algorithm to obtain the solution of the model, we compare and analyze the decisions and the corresponding profit. The study results indicate: a positive profit influence and an appropriate determination of the ordering quantity by distinguishing the deterioration gaps; a close relationship between shelf-replenishment point and LIFO purchasing behavior. The study offers some insights to improve backroom operations and re-optimize inventory decisions responding to such deterioration gaps and LIFO issue.

Keywords: *fresh produce; backroom effect; replenishment policy; ordering quantity*

Joint Condition-Based Maintenance and Inventory Optimization

Ruud Teunter

University of Groningen, Groningen, The Netherlands

Efficient (condition-based) maintenance planning and spare parts management jointly determine the effectiveness of a maintenance strategy and, thereby, balance system up-time and maintenance costs. An optimal policy for a single component is not necessarily optimal for all components, while a separate or sequential optimization of the maintenance and inventory decisions is also not guaranteed to yield the lowest costs. We therefore consider the joint optimization of condition-based maintenance and spare parts planning for multi-component systems. We formulate our model as a Markov Decision Process, and minimize the long-run average cost per time unit. A key insight from our numerical results is that the (s,S) spare part inventory policy, popular in theory as well as practice, can be far from optimal. Significant savings can be obtained by basing both the maintenance decisions and the timing of ordering spares on the system condition.

Inventory Dynamics in the Financial Crisis: An Empirical Analysis of Firm Responsiveness and its Effect on Financial Performance

Maximiliano Udenio[1], Kai Hoberg[2], Jan Fransoo[1]

[1] *Operations, Planning, Accounting & Control, Eindhoven University of Technology, Eindhoven, The Netherlands*

[2] *Kühne Logistics University, Hamburg, Germany*

The shock triggered by the 2008 financial crisis set up the largest natural experiment to test firms inventory management capabilities to date. Firms were suddenly confronted with an unprecedented collapse of demand, often with limited credit availability. A number of firms managed their inventories responsively, maintaining relative inventory levels fairly constant. Others built up considerable surplus inventory, and others reacted aggressively cutting their inventories. In this paper, we use firm-level empirical data from 1,278 public U.S. manufacturing firms for the period 2005-2011 to understand the drivers behind inventory responsiveness and explore the link between said responsiveness and profitability, market performance, and financial health. We find that on average, firms required six quarters to adapt to the situation. However, the responsiveness varies across sectors and firms. In particular, firms in chemical and electronics sectors required the most time to align inventories to the new realities. In addition, we identify lower liquidity, lower gross margins, and higher inventory predictability as key firm-level factors associated with higher inventory responsiveness. Firm size, often associated with superior inventory management capabilities, does not have a significant impact. Furthermore, we show that the impact of deviations from the normal inventory levels is not symmetric—inventory deficits appear to be more critical than inventory surpluses. Inventory reductions are associated with a decrease in the return on sales, an increase in the probability of bankruptcy, and a decline in short-term market performance. Our results confirm the view that managing inventories is indeed critical during crisis periods. Our findings, however, suggest that the short-term view of inventory reduction as an instrument of liquidity needs to be gauged carefully against the tradeoffs between different dimensions of short- and long-term financial performance.

Keywords: *inventory management; econometrics; panel data; financial crisis; economics of inventories*

Economics of Inventories

Creating Value with Inventories in a Commodity Supply Chain

Péter Kalocsai[1], **Péter Borbás**[2]

[1] *MOL Group, Budapest, Hungary*

[2] *Corvinus University of Budapest, Budapest, Hungary*

We present an industrial application of commodity inventory hedging. The question in focus is: how can derivative trading create value in a commodity (crude oil and its derivatives) industry with the assumptions of using multi-period and multi-plant LP optimization for generating inventory outlook for each planning period, seasonality of customer demand which can exceed production capabilities, limited storage space for multiple stock-piling purposes, and thriving efforts for minimizing employed capital in physical inventories.

Hedging is widely used in companies trading physically substantial amount of commodities in order to mitigate risk over an investment. The role of inventories is to fill the gap between geographical and timely disruptions of the customer supply process. The dynamics of inventory levels at the magnitude of bulk commodities produce significant price exposure, which requires turning to methods widely discussed in scientific literature.

After examining the relevant literature review we analyze different live cases when stock-piling proves to be financially beneficial if price exposure on inventories is ruled out. Our findings are presented as a combination of theory and empirical results. Though we are using theoretical results the emphasis is on the application rather than further contribution to mathematical theory. The results can be quantified, different scenarios are presented as the basis of inventory management decisions. The paper concludes in endorsing the active usage of hedging in order to support multi-period inventory decision making for higher profit levels.

Keywords: *hedging, stock-piling, application, price risk, commodities*

Taking Stock of Inventory Investment in Belgium

Geert Langenus, Raïsa Basselier

Research Department, National Bank of Belgium, Brussels, Belgium

This paper aims to improve the understanding of the movements in Belgian inventories, as reported by the National Accounts Institute (NAI), and analyses, in particular, to what extent a clear cyclical pattern can be discerned. We also assess whether relevant information on stock movements can be gauged from the high-frequency data, such as survey data, that are available in a more timely manner than the national accounts. Finally, we explore the role of explicit model forecasts of inventory investment in the context of the National Bank of Belgium's (NBB) biannual macroeconomic projection exercises and challenge the current technical assumption that typically sets all future contributions of inventory investment to GDP growth to zero.

We use the most recently published national accounts until 2015Q4 to build a linear regression model for inventory investment that includes an autoregressive component, a proxy for final demand and certain survey variables. We find that inventories initially seem to respond adversely to a contemporaneous demand shock, suggesting that it takes some time to modify production and, at first, additional demand will be met by selling off stocks. However, inventories show a more procyclical pattern thereafter, in line with the classical stock accelerator model. A dynamic forecast of the inventory investment as of 2013Q4 suggests that our model is able to capture the most important swings in Belgian inventory investment quite well. Furthermore, we find that certain survey variables are significant in estimating inventory investment, although the gain in the model's fit appears to be rather small. Finally, the model also seems to have anticipated revisions to the initial national accounts data in the recent period.

Turning to the role of inventories in medium-term macroeconomic forecasting, the explicit model forecast appears to outperform the NBB's current technical assumption of a zero growth contribution. However, this should not necessarily affect the GDP growth projections, but may rather point to a different composition of future GDP (with other demand components offsetting the current over- or underestimation of inventories).

Keywords: *inventory investment in the Belgian national accounts, growth contribution, cyclical pattern, survey data, macroeconomic forecasting*

A Non-Oriented DEA Game Cross Efficiency Model for Supplier Selection

Sungmook Lim

Dongguk Business School, Dongguk University–Seoul, Seoul, Republic of Korea

This study intends to propose a non-oriented DEA based game cross-efficiency approach for supplier selection. With a discussion on the choice of DEA models and approaches that are most appropriate for supplier selection, we propose a game cross efficiency model based upon the non-oriented variable returns-to-scale RAM DEA by adapting the existing game cross efficiency model based upon the oriented constant returns-to-scale CCR DEA. We develop the RAM game cross efficiency model and a convergent iterative solution procedure to find the best game cross efficiency scores that constitute a Nash equilibrium. We illustrate the proposed model with two data sets of supplier selection, and demonstrate that significantly different results are obtained when compared with the existing approaches.

Keywords: *supplier selection, data envelopment analysis, game cross efficiency, non-oriented model*

Sectoral Characteristics of Inventory Investment: An Empirical Study

Attila Chikán[1], Erzsébet Kovács[1], **Zsolt Matyusz[1]**, Magdolna Sass[2], Péter Vakhal[1]

[1] *Corvinus University of Budapest, Budapest, Hungary*

[2] *Institute of Economics, Hungarian Academy of Sciences, Budapest, Hungary*

The paper contains results of an exploratory study of inventory investments in a set of developed economies between 1970-2013. Several questions were addressed:

- What are the relevant sectors that influence inventory investment?
- Are there different patterns inside our examined time horizon and are there any marked breaking points?
- Countrywise, we investigate how former transition economies are related to traditional market economies in terms of sectoral characteristics and inventory investment.

We use OECD data and multivariate statistical methodology for the analysis of 32 OECD countries between 1970-2013, out of which six are former transition economies. Our preliminary results suggest that cluster analysis is an effective method to identify multiple patterns of sectoral characteristics related to the differences in inventory investment among groups of countries. Timewise, emerging clusters differ between the first (1970-1993) and second (1994-2013) subperiod. The results call attention to a number of research opportunities in the area.

***Keywords**: inventory investment, macroeconomic factors, classification, OECD countries, cluster analysis*

Horizontal Coordination under Information Distortion

Silvia Valeria Padilla Tinoco, Robert Boute

Research Center for Operations Management, Faculty of Business and Economics, Leuven, Belgium

Objectives of study: A two-company information sharing game is studied under horizontal coordination, using a can order policy[1]. We evaluate: (1) the influence of distorting information regarding demand rate on individual expected profits, (2) whether information distortion can be eliminated by selecting an adequate cost/gain allocation mechanism.

Materials and Methods: An embedded Markov chain model is used to obtain the exact number of orders triggered (or joined) and to obtain the steady-state inventory levels. Logically, a company may have an incentive to distort its demand information if this gives the company a higher expected profit. We evaluate three cost/gain allocation mechanisms: *the Shapley Value*[2], *the demand allocation rule*[3], and *the Linear rule*[4]. A Nash equilibrium calculation is performed to obtain the best strategy given a margin of error.

Results: We find how the demand distortion impacts both transportation and inventory costs of each individual company. By introducing a certain margin of demand error, the company may be able to influence the proportion of the costs/gains to be allocated. For the simple demand allocation rule no equilibrium is found.

Conclusions: Given that the expected profits strongly depend on both the margin of demand error and the selected allocation mechanism, these information distortions may reduce the benefit or even prohibit information sharing in supply chains. We find that by allocating the realized costs (in contrast to expected costs) of the coalition, the incentives to distort the information of demand are reduced.

Keywords: *Inventory management; Horizontal collaboration; Optimal policies; Information sharing; Mathematical modelling*

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Does ISO 9001 Certification Matter for Firm Performance? A Group Analysis of Greek Listed Companies

Efrosini Siougle[1], Claire Economidou[2], Sophia Dimelis[1]

[1] *Department of Informatics, Athens University of Economics and Business, Athens, Greece*

[2] *Department of Economics, University of Piraeus, Piraeus, Greece*

This study investigates whether the International ISO 9001 Standard certification affects the financial performance of listed firms. In particular, it is examined whether the possession of an ISO 9001 certification, which is considered indicative of a firm's quality management system, is eventually translated into an improvement of the firm's financial performance. A firm's financial performance is captured by several measures such as return on equity, return on assets, profit margin and asset turnover ratios. The analysis is based on an original data sample from all firms listed on the Athens Stock Exchange covering the period 1992 to 2013.

A comprehensive analysis is performed by categorizing the ISO 9001 certified firms into two groups: the group of firms that hold the certificate for all the years that are listed and the group of firms that initiate the certification at some point after entering the stock market. Furthermore, firms are classified on different technology prototypes and between manufacturing and services. The financial performance of both certified groups is compared to the financial performance of a control group of non-certified firms. The financial performance comparison is further performed within the two certified groups.

The findings indicate a positive and statistically significant association between ISO 9001 certification and firm's financial performance measures, for most of the proposed group classifications. The ISO 9001 certified firms exhibit significantly higher financial performance in comparison to the non-certified firms. The evidence suggests that the positive and statistically significant association of the ISO 9001 certification and the financial performance measures endures in the long run. Furthermore, the analysis reveals that firms initiating the ISO 9001 certification after entering the stock market are more benefited from the certification in comparison to firms holding the certificate for all the years that are listed. The findings of the study are apparent after controlling for sector and technology prototype effects.

The policy implication of the study is that the acquisition of the ISO 9001 certification is beneficial for listed certified firms regardless of the sector or the technology prototype categorization. The positive effects are not transitory and perpetuate in the long run creating better prospects for the adopting firms.

Keywords: *ISO 9001 certification; firm performance; group analysis; sector and technology prototypes analysis*

The Cash Conversion Cycle: An Empirical Analysis of its Impact on Supply Chain Performance

Maximiliano Udenio, Shaunak Dabadghao

Operations, Planning, Accounting & Control, Eindhoven University of Technology, Eindhoven, The Netherlands

The Cash Conversion Cycle (CCC) of a firm measures the time between a cash outflows and cash inflows. Specifically, it is calculated as a firms' total inventory plus receivable days minus its receivable days. It is commonly used as a measure of the ongoing liquidity of a company. By measuring the ability of a firm to meet its obligations, it serves as an indicator for the liquidity risk associated with a given inventory and cash management strategy. It is well documented that the cash conversion cycle has an impact on the firm value. Jose et al (1996) show that even without adjusting for size, the CCC and profitability measures are inversely related for most industry classifications. This observation is robust to different markets and firm sizes.

Firms use aggressive working capital management strategies in order to increase their firm value. A smaller CCC can be achieved by increasing the payable days, by decreasing receivable days, or by decreasing the days in inventory. In addition to immediate impact on the firm applying these strategies, these changes also have a direct impact on the firms upstream or downstream in its supply chain. In this paper, we use firm-level empirical data from 14,869 unique buyer-supplier pairs from public U.S. manufacturing firms for the period 1976-2015 to understand the drivers behind CCC changes and their effect on firm and supply chain performance. We study the effect of a change in the CCC of a firm on their supply chain partners, both in terms of impact on their own CCC as well as their profitability. The effect of change in the CCC creates a cash-flow bullwhip effect further up the supply chain. Additionally, we analyze the effect of firm-level traits such as inventory turnover, profit margins and liquidity ratios on the impact of the CCC changes in the supply chain. We derive general insights and recommendations.

Keywords: *inventory economics; empirical inventory research; cash conversion cycle; supply chain finance*

An EOQ-based Working Capital Minimization Discounted Cash Flow Model with Infinite Production Capacity

Thomas G. Yeung[1], Yuan Bian[1], David Lemoine[1], Nathalie Bostel-Dejax[2], Vincent Hovelaque[3], Jean-Laurent Viviani[3]

[1] *Ecole des Mines de Nantes / IRCCyN, Nantes, France*

[2] *University of Nantes / IRCCyN, Nantes, France*

[3] *IGR-IAE de Rennes / CREM, Rennes, France*

Companies need free cash flow to effectively react against uncertainty to ensure solvency. However, classical economic order quantity (EOQ) models only consider the physical flow of stock ignoring the financial flow of capital which can have significant cost. We introduce a first link between the EOQ problem and the financial aspects of working capital requirements (WCR). Working capital requirements are created due to the delay in payments from customers to cover costs due to procurement, production, and holding stock. An EOQ-based discounted cash flow model is established for single-site, single-level, single-product, infinite capacity cases with a WCR minimization objective. All unit cost parameters are assumed constant during the planning horizon. In our model, we first define the logistic costs which include purchasing, setup, production and inventory holding costs. We then define the financing cost of the WCR. This cost is the financial need and associated interest which covers the cost of logistic operations before the reception of customers' payments.

Purchasing, setup and production cost are all one-time payments for each production lot which must be financed once for the entire lot cycle. However, the inventory holding cost of each time period in each lot cycle must be continuously financed until receiving the customers' payments. Consequently, a cumulative effect of the financing cost for WCR in inventory holding is observed. In addition, this model allows us to evaluate the company's financial situation during the planning horizon by applying a new generic WCR model.

Numerical tests are provided to show the interest of applying our model of generating more free cash flow compared with the classical EOQ model which only minimizes logistic costs. Observations on the influential parameters of the optimal production quantity are also presented. An increase in the purchasing, production and especially the inventory holding unit cost will decrease the optimal order quantity. A greater discounted rate will also yield the same effect. A variation in the delay of payment from customers is shown to have only slight changes on the optimal production quantity, but a strong impact on the net present value of the total cost. Overall, it is demonstrated that the inventory holding cost has by far the greatest impact in an EOQ-based model that seeks to minimize WCF due to its cumulative effect and thus is minimized to the greatest extent possible.

Inventory Management

Optimization of Safety Stocks with an Order Service Level

Martin Albrecht

Paul Hartmann AG, Heidenheim, Germany

In practice, the order service level is a common performance indicator. Often customers request complete deliveries because of fixed costs in logistics and goods' income control. A usual way in practice to address this problem is to either choose equal service-level targets for each end item or to adjust different targets for A-, B- and C-articles based on gut feeling.

Both heuristics are suboptimal.

In this talk we provide a practical case study to illustrate this setting. Moreover, we propose new heuristics for safety stock calculation. The heuristics use item-based approximations for the order-based backorders. As the heuristics do not need detailed information about order bill-of-materials, their application scope is broad, and includes industrial-scale settings with a high number of orders. Computational results indicate that the heuristic solutions come close to the optimum.

Keywords: *inventory management, assemble-to-order, case study, order service-level, heuristic*

Backorders under Advance Demand Synchronised by Price Discount

Muzaffer Alim, Patrick Beullens

University of Southampton, Southampton, United Kingdom

We consider a single item, periodic review inventory system with advance stochastic demand. Regular customers place orders with a heterogeneous time ahead of their needs within a planning horizon. The focus in the literature has been on how to stimulate customers towards advance demand. Predicting how demand will shift can be problematic, however, and backorders may still occur. We focus on how a firm can address backorders under a given advance demand pattern by a mechanism of compensation that will benefit both the firm and the customers. We consider that the firm may offer a price discount to customers for accepting later deliveries. Discounts are only offered in some periods and to some customers when there is a benefit for the firm to postpone some of the demand. Customers may decline the offer, but then face the probability of a backorder. If they accept, they get a promised delivery date and financial compensation. In each period, the firm has to decide whether to offer a discount and to which customers, and whether to order and how much. We formulate the problem as a Net Present Value Markov Decision Process, and compare solving it by primal/dual linear programming and by backward induction algorithm. Numerical examples illustrate the properties of the state-dependent optimal policies obtained under capacitated and uncapacitated cases. We discuss how the firm can induce customers to reveal their true due date, i.e. why customer who wish to cheat cannot derive benefit.

Keywords: *inventory control, advance demand, price discount, markov decision, periodic lot sizing*

Jointly Optimal Buyer-Supplier Inventory Replenishment Decisions via Third Party Coordination

Kurt A. Masten, **Avijit Banerjee**

Department of Decision Sciences & Management Information Systems, Drexel University, Philadelphia, USA

The current supply chain literature provides ample evidence that significant improvements in supply chain surplus can be achieved if the constituent members (stages) of the chain jointly optimize the supply chain's inventory replenishment decisions, as opposed to deriving their own individual optimal policies independently. In addition to potential monetary gains, a variety of intangible benefits are likely to result from such joint optimization efforts. The bulk of extant research in this area suggest and explore a number of coordination mechanisms, such as quantity price discounts, etc., to improve upon purely competitive (arms-length) contractual arrangements. Recent research, however, has shown that such coordinated and integrated supply chain decision making rarely exists in practice, due to a lack of meaningful guidelines for practitioners, geared to the implementation of jointly optimal decisions in real world supply chains. Furthermore, current work often presupposes a spontaneous and effective effort towards coordination, undertaken by one or more members of the supply chain, which is not a common occurrence in the real world. This paper proposes and explores the novel use of an expert third party or agent, which plays the role of facilitating the integration and coordination of a dyadic (buyer-supplier) relationship. Through mathematical modeling and analyses, we show that the notion of such third party mediation can, not only result in improved profitability for the entire supply chain, but also represents a substantive contribution to the existing body of knowledge. Apart from achieving enhanced supply chain surplus, the use of an external agent is also likely to result in other notable benefits, such as neutral arbitration and protection of confidential business information. This paper suggests an optimization model, incorporating many costs not typically considered in arriving at inventory replenishment policies (e.g. the buyer's contractual commitment cost and the supplier's opportunity cost of capacity loss). We demonstrate the efficacy of our approach via a numerical study and perform a thorough sensitivity analysis with respect to some critical problem parameters.

Multi-Echelon Inventory Systems with Lost Sales

Marco Bijvank[1], Arjan Dijkstra[2]

[1] *University of Calgary, Haskayne School of Business, Calgary, Canada*

[2] *University of Groningen, Faculty of Economics and Business, Groningen, The Netherlands*

The worldwide out-of-stock rate is rather high with 7-8% in the retail industry. Empty shelve spaces are costing grocery stores and their suppliers about 200 million Euro a year within the Netherlands alone. In classic inventory models it is common to assume that excess demand is backordered (i.e., customers wait for a new delivery to arrive). However, studies analyzing customer behavior in practice show that about 75-85% of unfulfilled demand is lost. Inventory systems that include this lost-sales characteristic are more difficult to analyze and it is known that there is a lack of a clear structure in optimal replenishment policies for such systems.

In this presentation we study the control of a 2-echelon inventory system with a single depot and multiple non-identical retailers under periodic review. The retailers face demand from external sources. If there is excess demand at the retailers, any unmet demand is lost. The retailers are replenished by the depot, whereas the depot is replenished from an external source with ample supply. The replenishment orders of the retailers and the depot are delivered after a deterministic lead time, which can differ per retailer. The objective of this study is to determine the size of the replenishment orders, such that average cost per period for holding inventory and any penalty costs from lost sales is minimized.

First, we formulate a stochastic dynamic program to find the optimal replenishment policy. Next, we focus on base-stock policies to control the inventory levels for this system and show that such replenishment policies perform close to optimal. Furthermore, the performance of different rationing rules (i.e., rules how to allocate the on-hand inventory from the depot to retailers when the depot has insufficient stock to satisfy all retailers' replenishments) is illustrated. This strengthens the use of base-stock policies. However, it is non-trivial how to set the base-stock levels. Therefore, we develop a heuristic procedure to approximate the average cost per period for a given set of base-stock levels based on a decomposition approach. These approximations are subsequently used in a search procedure to find good base-stock policies. Initial results indicate that policies resulting from this approach are better than the best known base-stock policies in an equivalent setting with backordered demand.

Keywords: *lost sales, multi-echelon, optimal policy, base-stock policy, decomposition approach*

A Linear Programming Framework for Control of Tandem Production Lines

Ozge Buyukdagli, Murat Fadıloğlu

Yasar University, Izmir, Turkey

We consider the problem of production control and stock rationing in a make-to-stock production system with several customer classes that generate independent Poisson demands. The system consists of a tandem production line with a finished goods buffer at the end. At decision epochs, in conjunction with the stock allocation decision for the finished goods, the control specifies whether to continue or stop production at each workstation. We model the system as a Markov Decision Process (MDP) and then propose an equivalent linear programming formulation. This formulation enables us to solve larger models in reasonable times harnessing the power of the state-of-art optimization solvers.

We further impose the policy structure by constraining the solution space via an innovative introduction of a set of integer variables. Other than its theoretical attractiveness, the proposed approach, which can be implemented on state-of-art optimization solvers, brings in considerable savings in terms of computation time. Furthermore, the approach has the flexibility to be transferred to many dynamic control problems.

We present in this study, results of numerical experiments that cover both optimal control algorithm and performance evaluation models. Although we do not provide elegant structural properties and their proofs, we believe that there is a need for this kind of studies to understand the behavior of production/inventory systems and to obtain valuable insights about the dynamics involved. For many complex systems, there may not be that much of structure in optimal policies to characterize. However, this does not make the systems less valuable to investigate. In addition to the characterization of the optimal policies, we propose an efficient approach to optimize the parameters of the production control mechanisms, that are very applicable in today's manufacturing environments.

Keywords: *optimal control, tandem lines, markov decision process, linear programming, production/inventory control*

A Segmented Supply Chain Strategy for Distribution Network Design

Claire Chan[1], **Johannes Fichtinger[1]**, Nicky Yates[2]

[1] *WU Vienna, Department of Information Systems and Operations, Vienna, Austria*

[2] *Cranfield School of Management, Cranfield University, Cranfield, United Kingdom*

The literature on supply chain strategies has discussed lean and agile supply chain strategies for years. Whilst lean thinking mainly focuses on reducing waste in a system, agile strategies consider flexibility as the main objective. The underlying key assumption of both strategies differ: lean thinking assumes a stable, predictable environment in which the business operates in. The underlying key concept of agility is that of an uncertain, ever changing market environment. The idea is to include flexibility or the ability to quickly react to changes in market conditions in the very nature of the overall business strategy. In the meanwhile many authors have suggested that both strategies are not conflicting but both principles can be combined in a hybrid ("leagile") strategy.

In this paper we integrate distribution network design and modelling and inventory management considering a segmented supply chain strategy. The main contribution of this paper is to fill the gap between segmented supply chain strategies and operationalized network modelling. We present a distribution network model including the location decision, the allocation of end-market demands to warehouses and inventory management for multiple SKUs. Based on this model we compare lean and agile supply chain strategies as well as a segmented leagile strategy. We provide numerical analyses of the problem using simplified, stylized problem instances and report findings from a real-world large scale application at one of the largest European fast moving consumer goods companies.

Keywords: *lean, agile, leagile, network design, numerical study*

An Adaptive Risk Assessment Methodology for Maintenance Decision Support

Peter Chemweno[1], Liliane Pintelon[1], Peter Muchiri[2]

[1] *Centre for Industrial Management, Heverlee, Belgium*

[2] *School of Engineering, Dedan Kimathi University of Technology, Nyeri, Kenya*

Risk management performs an important decision support role in maintenance decision making. According to the IEC/ISO 31010, risk management provides decision makers with a framework for mitigating future uncertainties, where the framework consists of policies, procedures, and organizational arrangements that embed risk management throughout the organization. Core to the framework is the risk assessment process which consists of steps which allow the organization to systematically identify, analyze, evaluate, and mitigate risks in assets.

Yet, defining risk in operable assets, although assumed straightforward, is usually not so in the real-world setting. This challenge stems from a narrowed view of risk, hence influencing how risks are analyzed and mitigated in technical assets. More often, in practice, the definition and management of risks is largely expert-reliant, whereof conventional risk management approaches such as the Reliability Centered Maintenance are discussed.

In recent years, data-driven methodologies for maintenance decision support have emerged as an interesting domain, more so, given the enhanced collection of 'big data' owing to the adoption of computerized maintenance management systems (CMMS) in industry. Such systems have enhanced decision support on aspects such as generation of work-orders and partly, gaining statistical insights on maintenance risks, spare parts usage, or documenting maintenance costs. However, few data-driven methodologies are discussed in the literature which leverage on maintenance data for decision support in risk management. A particular concern in this regard relates to methodologies which encompass the four steps in risk management; 1) risk identification, 2) risk analysis, 3) risk evaluation, and 4) risk mitigation.

This paper proposes one such methodology and integrates different models at the different steps. Firstly, a Monte Carlo simulation framework is proposed for identifying, analyzing and prioritizing equipment failures. Secondly, a data mining framework is proposed for decision support in root cause analysis, whereof the root causes of the recurrent equipment failures are identified. Thirdly, a decision scheme is proposed for selecting appropriate maintenance strategies which mitigate the recurrent failures. The proposed methodology is demonstrated in the application case of maintenance datasets collected from a thermal power plant facility.

Keywords: *risk assessment; maintenance decision support; data mining; monte carlo simulation, root cause analysis; thermal power plant*

Dual-Channel Inventory Control with Cross-Channel Returns and Transshipments

Arjan Dijkstra, Gerlach van der Heide, Kees Jan Roodbergen

Department of Operations, University of Groningen, Groningen, The Netherlands

In this paper, we consider transshipments in a dual-channel supply chain for a product that is sold during a single sales season consisting of multiple periods. Transshipments between the two channels can be carried out periodically during the sales season. Products sold at a certain channel can be returned to both channels with a certain probability, which means that returns depend on demand.

The goal is to minimize costs during the sales season, which comprise of costs for holding stock, carrying out shipments, and having unsold stock at the end of the sales season. Using Markov decision processes, we study optimal transshipment policies during the sales season, as well as the optimal initial stock levels. We formulate a lateral transshipment heuristic, which we compare with the optimal policy and various other transshipment heuristics.

Our heuristic performs better than these other transshipment heuristics in a wide range of instances, showing the importance of taking into account cross-channel returns when making transshipment decisions.

Keywords: *returns, lateral transshipments, dual-channel, lost sales, markov decision process*

Introduction of IoT System to Real Time Production Change with Shop Inventory Management

Hiroaki Fujikawa, Kouhei Kominato

Tokyo University of Science, Tokyo, Japan

The fresh food commodities like sandwiches or lunch boxes sold in convenience stores must be replenished continuously in order not to face the shortage of commodities on the shelf. In general, most of the convenience stores keep their commodities in stock all the time. However excessive inventory may deprive expected profits and shortage of inventory may deprive not only revenue but also clients. Moreover demand of such fresh food commodities must be fluctuated with daily weather condition and unforeseeable matters. Then the factory of such commodities has to know the inventory level on the stores every moments and produce appropriate item and appropriate quantity of the commodities. It requires real time production changeover considering inventory condition in convenience stores and production line condition of such commodities. Production schedule of fresh food commodities must be prepared in advance and executed under the control of production manager who should grasp progress of each commodities and worker's conditions concurrently and make a decision how to share the excessive works among workers. It needs real time progress monitoring. We introduce monitor camera installed in factory line-side to get the image data which is taken all day long to find changeover instructions to workers. The image data from line-side monitor camera could be analyzed and grasped present progress conditions of each workers and each commodities by the developed software which encompass both image data and POS data from convenience stores. A developed software is examined under the test production line. Where the production items should be changed in accordance with the demand fluctuated condition. Production items have changed successfully to cover the ad-hoc emerging demand from stores within 60 minutes. We demonstrate feasibility of IoT system including image processing function and production schedule change decision making. Due to the development of our software, it is shown that production and inventory control IoT system can automatically control inventory shortage. That may decrease the number of production managers from production lines whose salaries are more expensive than workers and it is hard to standardize manager's skills.

Keywords: *Internet of Things (IoT), image processing, production item changeover, inventory management, convenience stores*

Consumers as Inventory Holders

Hisao Fujimoto

Department of Information Technology and Social Sciences, Osaka University of Economics, Osaka, Japan

The answer to a question "Who are the inventory holders?" may be as follows. Inventory holders are institutions like manufacturers, wholesalers, and retailers. Inventory models in macro and micro economics and inventory management almost treat inventories of firms. In distribution channel theory, consumers are included as distribution channel members in the whole distribution channels of consumer goods. It is because the factors determining members are the allotment of distribution functions as transaction, transportation, inventory, and information exchange.

This paper explores the importance of consumers' inventory for distribution channels. For this purpose, this study approaches consumers' shopping behavior and purchasing cycle. In addition, this study based on a buying behavior model and the data of local consumers' buying behavior of Japanese consumers, focusing especially elderly people, suggests that Japanese consumers can offer opportunities to local small retailers.

Consumer buying behavior can be described in three stags as (1) decision to buy, (2) action to buy, and (3) consumption. Consumers may synchronize their consumption intervals of many kinds of goods to make an efficient buying plan. Before stage (2), inventories are stocked in retailers, and inventories are hold by consumers after stage (2) till their consumption.

The consumer buying behavior model here has two dimensions: the axis of space and the axis of time. On this two dimensions, consumer buying behaviors can be divided into following four types: frequent centralization buying, frequent decentralization buying, non-frequent centralization buying, non-frequent decentralization buying

Consumers who carry out the "frequent decentralization buying" are congenial to small residential retailers. These consumers tend to complete their daily shopping within their local communities. Especially elderly consumers' behavior can be classified into the "frequent decentralization buying". They may be not so conscious of price, but conscious of high level services. Small retailers can provide them with many kinds of services as important social supports. Several small retailers already have begun to recognize the importance of elderly consumers and grapple with new retail services such as the convenient ordering and delivery systems. When retailers can serve to consumers' access and frequent purchasing, it can reduce the burden of consumers' stock keepings.

Keywords: *inventory, consumer buying behavior, purchasing cycle, elderly consumer, postponement and speculation*

Modeling and Analysis of Primary and Secondary Markets in a System with Random Unit Costs

Refik Güllü, Yücel Gürel

Bogazici University, Industrial Engineering Department, Istanbul, Turkey

In this talk we consider a system where the customer demand can be partitioned into two segments: a primary and a secondary market. These kinds of systems are observed, for instance, in technology intensive products or services where the primary market, being more loyal, is generally not too sensitive to the pricing of the product or service. While the primary market customer demand occurs right after the introduction of the product, the secondary market customer demand typically occurs after the product matures, and these customers are much more sensitive to changes in the sales price. The purchasing costs of technology intensive products very much depend on the spot currency exchange rate, and hence can be modeled as a stochastic process. Consequently, the sales price for the primary market customers can be assumed to be a mark-up of the spot purchasing cost of the product. On the other hand, as the secondary market customers are more sensitive to the sales price, a demand model, where the customer demand explicitly depends on the selling price would be more appropriate. **The objectives of this study** are (1) to model the described system, (2) to find the optimal initial quantity to stock, and (3) to determine the optimal sales price for the secondary market customers.

In order to achieve these objectives, **as the modeling method**, we derive the expected profits of the system over the demand periods of primary and secondary customers, respectively. As the sales quantity for the secondary market customers is bounded by the product availability at the end of primary sales period, the initial purchase quantity would have an impact on the sales price for the secondary market customers. We also carry out a computational study to highlight important managerial insights. **Our results** reveal important information regarding the impact of joint determination of secondary market price and initial purchase quantity, and the effect of cost volatility on inventory and pricing decisions. ***In conclusion***, our model provides original analytical findings, together with important managerial insight for a system with dual customer base, and with demand and cost uncertainty.

Keywords: *optimal order quantity, primary and secondary markets, cost uncertainty, volatility, price dependent demand modeling*

An Inventory Problem with Processed and Non-Processed Products of Same Perishable Goods

Hiroaki Ishii

Department of Mathematical Sciences, School of Science and Technology, Kwanseigakuin University, Sanda Hyogo, Japan

We consider two types of products for a same perishable goods given as follows:

One type is non-processed one and so it has single life time period life time.
The other is processed one and it has two period life time. That is, for proceeded one, there exists, one with remaining life time one in the stock and that with remaining life time two (newly delivered). One example is tomoto delivered before matured one. Customer who prefers delicious one (that is, sensitive to taste) usually buys non-processed one but if it is sold out, p percent of customers who cannot buy non-processed one buy processed one with remaining life time two. Customer who prefers cheaper price one usually buys processed one since it is cheaper compared with non-processed one. Customer sensitive to taste is served before that sensitive to price.

(2) Ordering takes a place at the start of the period under the condition that some processed products with remaining life time one are in the stock. The ordering amount of the non-processed product is denoted with x_1 and unit ordering price is c_1. Similarly ordering amount of processed one is denoted with x_2 and unit ordering cost is c_2. x_1, x_2 are decision variables.

(3)Issuing policy is LIFO for the processed ones, that is, customer buys products with remaining life time two first and if these are sold out, the customer buys the old one, that is, one in the stock. Unit selling price of non-processed one is r_1 and those of the processed one with remaining life time two (newly delivered one), remaing life time one r_2, r_3 respectively. We assume that $r_1 > r_2 > r_3 > 0,\ r_1 > c_1, r_2 > c_2$

(4) The non-processed one and processed one with life time one that are not purchased by the customer is discarded at the unit cost θ. While processed one with life time two that are not purchased by the customer is stocked with unit cost h.

(5) The demand D_1 of the customer for non-processed one and that D_2 for processed one are nonnegative random variables. Their cummulative distribution functions are $F_1(D_1), F_2(D_2)$ respectively and their density functions $f_1(D_1), f_2(D_2)$ respectively where $F_1(0) = F_2(0) = f_1(0) = f_2(0) = 0.$

(6) Under the above setting with a stock of processed one, we calculate an expected profit function $E(x_1, x_2)$.

Then we investigate an optimal ordering quantities x_1, x_2 depending on the condition of stock for the processed one.Finally we discuss many further research problems including sensitivity of p, selling prices, etc.

Keywords: *non-processed and processsed products of same perishable good, sensitivity customers to freshness and price, stochastic demands, expected profit function, optimal ordering quantities*

Intertemporal Interactions between Inventories and Firm Performance – An Empirical Analysis of Manufacturing Firms

Florian Kaiser, Robert Obermaier

Chair for Business Economics, Accounting and Managerial Control, Passau, Germany

Objective: The phenomenon of inventory leanness is subject to a rich body of research articles over the last two decades. Focusing on the relationship of inventory management and financial performance the results of previous studies are mixed, which could be due to the fact, that the underlying causality remains unclear. While most of these studies investigate the effects of inventory management on firm performance it still remains unclear whether the causality holds this way or the other way around, although firm performance could affect future investments in inventories as well. Hence, the purpose of this paper is to investigate empirically the causal logic of the relationship between inventory holding and firm performance.

Materials and Methods: This empirical study is based on data from the German manufacturing sector using vector autoregressive and vector error correction models combined with the concept of Granger causality.

Results: We find intertemporal interactions among inventory management and firm performance which are analyzed and discussed in detail. Results show that there is a bilateral relationship between inventory holding and firm performance, i.e. that inventory holding affects financial performance and financial performance affects inventory holding as well.

Conclusions: We highlight the relevance of firm performance for future decisions on inventory holding and provide arguments for this direction of causality. One of the most important arguments for a bilateral interaction of financial performance on inventory holding is that high performing firms can afford holding higher inventories in order to run their processes properly and providing higher service levels to customers resulting in higher performance.

Keywords: *inventory management, firm performance, intertemporal interactions, vector autoregression models, granger causality*

Control of a Continuous Production Inventory System with Production Quantity Restrictions

Steffen T. Klosterhalfen[1,2], Falk Holzhauer[3], Moritz Fleischmann[4]

[1] *Robins School of Business, University of Richmond, Richmond, USA*

[2] *BASF SE, Ludwigshafen, Germany*

[3] *Daimler AG, Mannheim, Germany*

[4] *Business School, University of Mannheim, Mannheim, Germany*

In the chemical industry many production assets run continuously around the clock. Due to prohibitively large costs for shutting down and ramping up, such actions are only taken when absolutely necessary, e.g., for maintenance or cleaning purposes. The only feasible adjustment of the production process refers to the rate at which the chemical reaction is run. As long as this rate stays within a certain range the quality of the output is not affected. Consequently, the production quantity can be steered via the run-rate within certain limits. Due to technical restrictions as well as wear and tear a run-rate adjustment is only made at regular intervals. In the specific application that motivated this research the supply chain planner discusses with the production head at the beginning of each month at which speed the reactor should operate in this particular month. For such a production system a control rule is to be suggested as well as an algorithm for the control parameter determination that helps the planner to decide on the production quantity in order to achieve a predefined service level target.

We show that the system under consideration can be interpreted as a periodic-review inventory model with an order band. The term order band describes the feasible periodic production/order quantity corridor. This insight allows us to leverage the already existing results regarding the optimal control rule, which is a modified base-stock policy. In order to obtain the base-stock level the existing contributions use simulation optimization methods, in particular Infinitesimal Perturbation Analysis. For our purposes this method is not appropriate, however. From simulation runs that we conducted of this particular type of inventory system we found for various parameter settings that it takes a very large number of time periods, sometimes over several million time periods, to reach the steady state. In addition, the planner is interested in a solution implementation in a known software environment, ideally a spreadsheet tool. Therefore, we propose a different solution algorithm based on a modification of the moment-iteration method by de Kok (1989), "A moment-iteration method for approximating the waiting-time characteristics of the GI/G/1 queue", Probability in the Engineering and Informational Sciences, 3, 273-287. From a numerical study we find that the solution algorithm performs very well on a large set of parameters.

Keywords: *continuous production, inventory control, modified base-stock policy, moment iteration, order band*

Joint Pricing and Inventory Decisions for Perishable Substitute Products: A Case Study from Food Industries

Mohammad Amin Edalatpour, **S.M.J. Mirzapour Al-E-Hashem**, B. Karimi

Amirkabir University of Technology, Tehran, Iran

Inventory policies play an undeniable role in various entities of a supply chain. Suppliers, manufacturers, dealers, retailers and eventually customers are dealing with inventory in a way. On the other hand product pricing is an important subject that influences selling and purchasing behaviors, so it should be noticed precisely. Accordingly determining an optimization model that considering inventory and pricing decisions concurrently can be very useful for any kind of business. In today's market, various types of relations are linking products, such as independent, complementary and substitute. Substitute goods defined as goods which selling, consuming and consequently price trends compete with each other and follow a negative correlation. Also due to the more complex products and requirements, which can be used interchangeably and make the markets more complicated because of inspiring business competitions, these kinds of products are obtaining more attention among academics and specialists and can be found in vast areas of daily life and various industries. Also, many kinds of products due to the differences in features like expiration date, holding conditions, special transportation system and other reasons categorized as deteriorative or perishable items.

In this paper, a multi-product inventory model is presented for perishable substitute products which optimize the revenue function of the inventory system. The substitution relation among products is applied in the model through assuming the demand function as a function of the product and its substitute's prices', the degree of substitution between the products and the price sensitivity. Considered models combine substitution and perishability specifications of the products and determined each product optimal price and inventory variables. To illustrate the application of the proposed model, a hybrid numerical example is presented and solved by two exact and heuristic algorithms incorporating data from one of the most popular national food brands in Iran. The results are compared, and the sensitivity analysis and managerial insights with respect to the different proposed parameters are represented in detail. Finally, the effects of model parameters on variables values are summarized in conclusion.

Keywords: *inventory, pricing, substitution, perishable, optimization*

"Thinner, Lighter, Faster ..." and the Way Forward for Time Series Extrapolation Methods

Konstantinos Nikolopoulos, Evangelos Spiliotis, Vassilios Assimakopoulos

Bangor Business School, Bangor University, Bangor, United Kingdom

Research in time series extrapolations methods is quite fragmented. Improvement in forecasting performance is very detrimental and most benefits in the process come from either better information sharing or management judgment. Any new approach has to compete and beat the two best established benchmarks in the field: Damped Trend Exponential smoothing and the Theta method dating from 1985 and 2000 respectively. In this research paper we aspire to discuss how a new extrapolation should be developed via using elements and paradigms from the most successful ones and we do propose such a new method. We employ the decomposition approach use d in the Theta methods but instead of using a linear trend we allow from more flexibility and use a set of non-linear trends. Furthermore instead of starting from the original data we apply smoothing first and thus we end up with a much better starting point from our extrapolation, something that the Naive method has proved in many empirical investigations how important it is. We evaluate the new proposition in the M3 competition data with very promising statistical accuracy results. Bottom-line, for any new method to compete with the existing benchmarks it has to be better... at everything; in the worlds of late Steve Jobs: thinner. lighter, faster....

The Integrated Approach of Order Picking System in Warehouse Management: A Case Study

Judit Oláh[1], Júlia Pauluk[1], József Popp[2]

[1] *Department of Logistics Management, Institute of Applied Informatics and Logistics, Faculty of Economics and Business, Debrecen University, Debrecen, Hungary*

[2] *Institute of Faculty of Economics and Business, Debrecen University, Debrecen, Hungary*

Order Picking System is a warehouse management process module which helps to put together the range of goods from warehouse stocks based on individual orders. This module is the most complex and critical process which calls for the most living labour input, it is difficult to plan, there is a higher risk of error and delay puts performance at risk. Locating technologies represent one of the main resource and time saving opportunities of Order Picking System.

The examined international tyre manufacturer enterprise constantly keeps pace with the development required by the market; therefore, the number of manufactured tyres grows year by year. The fundamental problem of this enterprise is to identify the order that the order picking emloyee should follow when accessing all locations in the shortest possible time and route. In order to shorten the picking travel time, we initiated the change of the order of products on the order picking list. The order picking list based on the numerical increase of the original ascending CAI (Code Article International) identifier was switched to the order picking list based on the alphabetical order of storage locations. Four categories were established based on the number of goods of each list and the involvement of storage locations. Category "A" includes the preparation lists on which the number of prepared goods is between 60-90, while the same amount is 20-60 in category "B", 10-20 in category "C" and 1-10 in category "D".

It was concluded during the research that if storage location involvement is below 10-15, the amount of time to be saved is minimal (0-4%). However, even up to 11-13% time can be saved in the case of storage location involvement of 70-90. It was concluded that preparation has to be done in as many storage locations as possible during commissioning. The higher the number of goods is, the more time can be saved. Consequently, preparation performed based on the desired new commission list is more effective at higher storage location involvement. Employees performing Order Picking System can obtain an ideal route with a order picking list based on the ascending alphabetical order of storage location names, since these employees enter a room only if the good in the given room is on the order picking list.

Keywords: *warehouse management, order picking list, order picking system, time saving, storage location*

An Empirical Investigation of the Bullwhip Effect on a Complex Three-Echelon Supply Chain

Arianna Alfieri, **Erica Pastore,** Giulio Zotteri

Politecnico di Torino, Torino, Italy

The increase of demand variability along the supply chain has a huge impact in companies, where demand fluctuations make the forecasting and planning processes harder, especially in the upstream levels. We present an empirical analysis on the Bullwhip Effect (BE) identification on more than 30,000 SKUs of a three-echelon European automotive spare parts supply chain. With our analyses, we aim at shedding some light on the incentives that lead to the smoothing/amplification of demand variability.

We analyse the bullwhip effect on two different aggregation levels. First, we evaluate the global BE along the supply chain, calculated on the total demand series. We aim at identifying the intensity of the BE in each level and at investigating if the empirical context reflects the literature results concerning a monotonic demand variability amplification through the echelons. Secondly, we increase the level of detail and we study the BE on the single SKUs. The objective is to measure how the intensity of the BE varies across products. Also we want to investigate what product characteristics tend to make the bullwhip effect stronger.

Preliminary analyses confirm the presence of bullwhip when considering the total demand series. Demand variability amplifies through each echelon, especially moving from dealers to local warehouses. This first outcome provides us with insights on the incentives structure of the company. In fact, dealers are independent entities. The strong increase of demand variability from independent nodes to the distribution company is probably due to the incentive structures given to dealers. In particular, demand at the top level is found to be more than twice variable than the final sell-out. Further analyses will be devoted to understanding the final effect of such a great demand variability on the suppliers' behaviour. Also, the comparison of the BE distribution among different demand classes calculated on single SKUs gives us a very interesting perspective. The BE is higher for fast moving products than for slow movers. The combination of the two results suggests that dealers tend to decouple demand and supply for fast movers. Thus, when they are given an incentive to forward buy, they prefer to forward buy fast moving items. Further research will be devoted to prove the validity of our hypothesis on dealers' behaviour and investigate the contribution of other product characteristics on the BE.

Keywords: *Bullwhip effect, inventory management, supply chain, empirical investigation, information distortion*

Integrated Inventory and Capacity Management for Cabin-Based Transport Systems

Gerald Reiner[1], Christian Bettstetter[2], Pasquale Grippa[2], Andreas Kercek[3], Bernhard Oberegger[1], Thomas Schlechter[4], Evsen Yanmaz[3]

[1] *Universitaet Klagenfurt, Department of Operations Management and Logistics, Klagenfurt, Austria*

[2] *Universitaet Klagenfurt, Institute of Networked and Embedded Systems, Klagenfurt, Austria*

[3] *Lakeside Labs, Klagenfurt, Austria*

[4] *Skidata, Austria*

Objectives of study: Public transport systems, like underground trains and cable cars, are important components of urban and recreational infrastructure. From the user perspective, such systems should transport passengers to their destination in a comfortable and fast manner (e.g., keeping waiting times low). From the perspective of the system operator, the throughput, up-time, reliability, robustness, and safety must be high. The objective of this study is to develop an efficient and effective access management, which regulates the entry of passengers to the transport system via gates under joint inventory (waiting areas) and capacity constraints. The objective is to reduce waiting times and improve fairness and, therefore, enhance the attractiveness of the system to, consequently, optimize the long-term revenue (under consideration of customer satisfaction, etc.) for the system operator.

Materials and Methods: The transport system is modelled as a queueing network with several interconnected queues associated with waiting and boarding areas in the stations. At the stations, passengers can enter the system, leave the system, or interchange transport lines. Therefore, the queues can be filled either by passengers entering the stations or by passengers changing lines. Empirical representative demand patterns will be provided by a leading provider of access solutions.

Results: The number of passengers across the network will be tracked using various different types of sensors to optimize the passenger flow under consideration of passenger waiting, time, etc.. The particular challenge lies in the fact that the system must adapt to highly volatile demand conditions. For development and validation of developed distributed as well as centralized entry management algorithms, we will set up a simulation model reflecting this particular queueing network problem, and we will study the influence of the algorithms on the performance of the transport network.

Conclusions: The developed adaptive system will be capable of optimizing the performance of cabine-based transport systems. Foundations for innovative solutions for the current state of transport systems will be provided.

Keywords: *queueing systems, simulation, cabin-based transport systems, adaptive system*

Acknowledgement*: This work was supported by Universitaet Klagenfurt and Lakeside Labs GmbH, Klagenfurt, Austria and funding from the European Regional Development Fund and the Carinthian Economic Promotion Fund (KWF) under grant KWF 20214 u. 3520/ 27678/39824.*

Optimal Management of Infrequent Demand Spare Parts for the Automotive Industry

Chiara Ronzoni, Andrea Ferrara, Andrea Grassi

Università degli studi di Modena e Reggio Emilia, Reggio Emilia, Italy

The study focuses on the automotive spare parts management. The automotive spare parts supply chain is structured in different echelon: the producer at the first level, the distributors at second level, and the final resellers at the third level. Our work focuses on distributors, being these actors the ones that face the most important logistic problems. In fact, they have to guarantee the highest service level to final customers that frequently need spare parts with urgent delivery. The idea is to create a network in order to minimize the stock avoiding lateral transshipments.

Our study presents a model which objective is to allocate a set of products to a player of the network minimizing the total costs he has to face during the period and, at the same time, ensuring a final total cost equal for each player. The proposed model is based on a previous work by the same authors, in this paper we propose an extended version of what we called "The Second Layer" and we will present the case of products' obsolescence and new products introduction.

In order to consider the possibility that after a time some products can become obsolescent, we introduce some changes in the basic model, assuming that when the obsolescent product sorts the network, it has no stock left in the network. With this aim an input matrix of presences it is needed. Other possible situation is that during the observation period N a new product needs to be introduced in the network.

Concluding, our aim is to present an extended mathematical model, starting from a previous work from the authors which purpose is to address the optimal management of infrequent demand spare parts in the automotive industry. The proposed model assumes the optimal management policy for the products known, and focuses on the allocation of the products among the players of a collaborative network. We present a work where we take into consideration also variations in the mix of products.

Keywords: *spare parts, automotive, inventory, model, supply chain*

A Continuous-Review Inventory Model with Disruptions and Reorder Point

Arya Sevgen, Fatma Zeynep Sargut

Izmir University of Economics, Balçova, İzmir, Turkey

We study a two-echelon continuous review inventory problem of a retailer and a supplier. It is an extension of economic order quantity model with lost sales and reorder point when both supplier and retailer are subject to random disruptions. It is assumed that supplier have two states which are available (ON) and unavailable (OFF), modeled with Markov chain. Whereas, if retailer is disrupted, all on-hand inventory is destroyed but afterwards retailer recovers immediately to serve the customers. All unsatisfied demand at retailer is assumed to be lost. In this study, the objective is to identify the optimal inventory policy for the retailer and investigate the importance of a non-zero reorder point for the retailer.Utilizing Renewal Reward Theorem, expected total cost per unit time is derived. We analyze the sensitivity of the optimal values of expected cost per unit time, order-up-to level, and reorder level to different problem parameters. The problem parameters we investigated are unit holding, unit lost sales, fixed and variable ordering, supplier disruption and recovery rates, retailer recovery rate, and demand rate. We use 1728 test cases in Sargut and Qi (2012) and another data set including 15360 test cases. In computational experiments, we also compare our solution with the optimal classical economic order quantity and we conclude that our model gives better or the same optimal average expected cost than EOQ. We conclude that adding a non-zero reorder point to the inventory policy is meaningful when supplier disruptions are more frequent than retailer disruptions. If the ratio of supplier disruption rate to recovery rate is greater than one, a positive reorder point can be optimal.

Keywords: *inventory control, disruption, economic order quantity, reorder point, lost sales*

Multi-Item Inventory Systems with Selective Use of Imperfect Advance Demand Information

Engin Topan, Tarkan Tan, Geert-Jan Van Houtum

Industrial Engineering & Innovation Sciences, Eindhoven University of Technology, Eindhoven, The Netherlands

We consider a multi-item inventory system subject to an aggregate level service constraint. A monitoring mechanism makes it possible to collect advance demand information (ADI) at a certain cost for each item. ADI might be imperfect because (i) it may be false, (ii) exact timing of the demand occurrence is unknown and (iii) there are demand occurrences for which ADI cannot be collected. We allow for clearing excess stock built up due to imperfectness. Imperfectness of ADI, collection costs and aggregate level service level service constraint make ADI collection interesting only for a selection of parts.

We propose a multi-item model to select items to be monitored and to find the optimal inventory policy for each item minimizing average long-run ADI collecting, inventory holding, regular and emergency order and return costs. We propose an exact optimal solution approach based on the decomposition of the model into single-item problems. For the single-item problem, we characterize the optimal ordering and return policy and show that the optimal policy is a state-dependent two-sided base-stock policy. In an extensive computational study, we investigate the value of imperfect ADI and characteristics important in the selection of items for which ADI is collected. We reveal that three imperfectness measures are quite influential however they are not equally important. Returning excess inventory is effective in coping with imperfect ADI. Selection of items to be monitored appears to be more complicated than thought to be since there are many factors effecting this decision, each interacting with others.

Keywords: *imperfect advance demand information, inventory, multi-item, optimal policy, value of information*

Optimizing Stock Levels for Rental Systems with a Support Depot and Partial Backordering

Gerlach van der Heide, N.D. Van Foreest, K.J. Roodbergen

Department of Operations, University of Groningen, Groningen, The Netherlands

Various rental systems, such as public libraries and tool rental companies, have a support depot for storing rental products at low cost and carrying out expedited shipments in response to stock-outs at local warehouses. Rental systems commonly introduce partial backordering, i.e., a limited number of demands can be backordered while additional demand is lost. We fully characterize costs and optimal base stock policies in cases with one support warehouse and one local warehouse and provide upper bounds for base stock levels in the general system. In small systems optimal policies can be obtained by enumeration. For larger systems we develop a greedy algorithm based on approximate cost evaluations. The resulting base stock policies have costs within 0.2% from optimality on average. Among others, experiments demonstrate that existing methods for no backordering may lead to poor solutions in case of partial backordering and that partial backordering can be an effective means for rental systems to reduce lost demand.

Effect of Online Retailer's Return Policy on Purchase Intention

Jing Zhu, Xiaorong Fu, Qinghong Xie

Southwestern University of Finance and Economics, Chengdu, Sichuan, China

Objectives of study: This paper explores relationships between consumer perceived leniency of an online return policy, perceived risk, trust, and consumer purchase intention.

Materials and Methods: The hypothesized relationships of this model are tested with data collected from 202 questionnaires by using AMOS.

Results: The findings suggest that consumer perceived return policy is directly related to online purchase intention and trust. Positive and significant correlation between trust and online purchase intention has also been identified. Moreover, this study reveals the negative correlations between consumer perceptions of the leniency of a return policy and perceived risk. However, the correlation between consumer perceived risk and purchase intention is not significant, which is consistent with previous research.

Conclusions: The contribution of this paper is tri-fold: First, we introduce a notion of consumer perception of the leniency of a return policy, which can be used to measure the effectiveness of online return policy. Second, consumer perceived risk and trust have been used to analyze the impact mechanism between consumer perceived return policy and online purchase intention. Especially, we find a significant moderating effect of trust on the relationship between consumer perception of the leniency of a return policy and online purchase intention. Finally, we provide managerial implications for online retailers from two aspects: i) the length of return time window and the convenience of return process could attract more online consumers. Online retailer can increase the sales by offering enough return time and a convenient return service such as door-to-door return service. ii) Compared to other aspects of return, refund amount has no significant effect on consumers' purchase intention, trust, and perceived risk.

Keywords: *e-commerce, return policy, purchase intention, trust, perceived risk*

Mathematical Models of Inventories

Determining the Optimal Customization Levels, Lead Times and Inventory Positioning in a Vertically Differentiated Market

Parisa Bagheri Tookanlou, Hartanto Wong

Department of Economics and Business Economics, School of Business and Social Sciences, Aarhus University, Aarhus, Denmark

In this paper we study a manufacturer's product line decisions when selling customized products to a market where consumers are vertically differentiated. The product has two attributes based on which a consumer's product valuation is determined. The first attribute is customization level, defined by how far consumers are involved in the value chain. A higher customization level is achieved when consumers are involved further upstream in the value chain. The second attribute is delivery lead time which is influenced by the customization level. It is expected that the delivery lead time will be longer when the customization level is increased, and vice versa. The vertically differentiated market is represented by two segments. Consumers in the first segment highly value customization level and are not so concerned with lead time. On the contrary, consumers in the second segment is very concerned with lead time and put less importance on customization level. Given such product and market characteristics, the manufacturer must make a choice whether to offer a single customized product or to exploit the benefits of quality-based segmentation by offering two different customized products. Different from most existing work in the product line design literature that neglects the operational aspects attached to the value chain, in this paper we consider the inventory positioning decision along the value chain which is interdependent with the customization level and lead time decisions. The model developed provides insights into the conditions under which the quality-based segmentation strategy is preferable when customization level, lead time and inventory positioning are interdependent. Our model can also be used to help determine which production processes in the value chain should be given priority when there is a lead-time reduction project on a limited budget and the numerical results demonstrate that offering two different customized products is profitable rather than offering single product strategy targeted both segments for the manufacturer in a vertically differentiated market.

Keywords: *product line decision, mass customization, inventory positioning, vertically differentiated market, quality-based segmentation*

Planning for Shortages? Net Present Value Analysis of Models with Backorder Costs

Patrick Beullens[1], Yousef Ghiami[2]

[1] *University of Southampton, Southampton, United Kingdom*

[2] *Vrije Universiteit Amsterdam, Amsterdam, The Netherlands*

Should a firm plan its inventory replenishments such that shortages purposefully occur? Can such answers be found from deterministic average cost inventory models? It is well recognised in the literature that unit costs of backorders or lost sales are difficult to measure and that this is a serious draw-back for getting real insight from such models. Since Grubbström (1980) we know that answers to such questions can be found by developing Net Present Value models based on cash-flow functions. While this technique has been used to gain insight into the nature of holding costs, hardly any work so far has been done on using this technique to develop insight into the cost of backorders and lost sales.

We consider a number of very plausible payment structures in backorder situations and use this to develop a series of NPV models which can be compared with a series of classic models with linear and fixed backorder costs, and with full and partial backordering. We find that the classic average cost EOQ models with shortages are in general much more robust than the classic average cost EPQ models with shortages. The specification of backorder and shortage costs in EOQ models is intuitive and can be based on only exogenous financial information. In EPQ models, the unit backorder and shortage costs are dependent on other model parameters such as the annual demand rate, production rate, and backorder rate. The average cost EPQ models need extra terms in their cost function in order to account for all opportunity costs and rewards that depend on the decision variables.

***Keywords**: linear and fixed backorder costs; partial backordering; average cost; net present value; EOQ and EPQ models*

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Emergency Service Logistics: Network Design and Dynamic Dispatching

Herman Blok, Joachim Arts, Geert-Jan van Houtum

Operations, Planning, Accounting & Control, Eindhoven University of Technology, Eindhoven, The Netherlands

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Emergencies such as the breakdown of an MRI-scanner or a domestic fire demand a timely response. This means that the resources required for addressing such incidents (spare parts and fire trucks, respectively) need to be stored in relative proximity of potential incidents and dispatched on short notice. This requires a network of resources in several storage locations. Owners of such Emergency Resource Networks (ERNs) face three issues: (i) Where should resources be stored, and how many resources need to be available at each location? (ii) How should resources be dispatched in response to an emergency? (iii) Can the performance of the system be improved by proactive relocation of resources?

In this talk we will focus on planning at the tactical layer. Suppose the dispatching rules at operational level are fixed. How many resources should be available at each location?

Interactions between Flow of Human Resources in Functional Regions of Supply Chain Nodes and Flow of Inventories in Processes of Global Supply Chains

David Bogataj[1,2], Samo Drobne[1], **Marija Bogataj[2]**

[1] *University of Ljubljana, Ljubljana, Slovenia*

[2] *MEDIFAS, Šempeter pri Gorici, Slovenia*

In the paper we shall demonstrate that the combination of MRP Theory which enable to study flow of goods, and gravity models of labour commuting embedded in production functions of activity cells in the supply networks enable the mathematical formalization of Castells' concept known as "reconceptualization of new forms of spatial arrangements under the new technological paradigm", based on Ruggie's work on "Problematizing Modernity in International Relations" and Arrighi's further study of interactions between spatial entities and non-territorial global economic space. Here the idea of the functional region as a unit in the space-of-places is considered. The nodes of a supply chain are assumed to be in the centers of functional regions. The factors which influence availability and costs of human resources are studied on the bases of Lowry-like model and the results are embeded in the production functios associated with nodes of a supply chain. The inventories in the process are described as the items in the flow of MRP model. The aim is to construct a model which enables regional authorities and managers of global supply chains to analyse and forecast the impact of improvement of accessibility of nodes to human resources in functional regions on supply chains.

Here the net present value (NPV) of inventories in process in a global supply chain and human resources in functional areas in the nodes of supply chains is the criterion function. Therefore, the paper shows that studies of interactions between the supply chain flows (flow of items, information and financial flows) and human resources as commuting flows in a functional region could support a more sustainable economic growth.

***Keywords**: MRP theory, Lowry-like model, human resources, net present value, flow of items*

An Embedded Markov Chain Approach for the Analysis of (Q, R, K) Replenishment and Rationing Policy

Önder Bulut, Murat Fadıloğlu

Department of Industrial Engineering, Yaşar University, Izmir, Turkey

Rationing is an inventory policy that allows prioritization of demand classes. It enables the inventory system to provide higher service levels for critical demand classes. Companies often wish to provide different service levels to different customers in order to achieve higher operational efficiency. The underlying motivation usually is the difference in service level requirements or shortage costs for customer classes. We consider a backordering inventory system that experiences demands from two customer classes according to two independent Poisson processes. Inventory is replenished according to (order quantity, reorder-point) (Q, R) policy. It is assumed that replenishment orders arrive after a deterministic lead-time. If there is inventory on-hand, arriving Class 1 demands are instantaneously satisfied. They are only backordered when on-hand inventory depleted, i.e., the rationing level for class 1 is zero. Arriving class 2 demands are instantaneously satisfied if the on-hand inventory level is above the critical rationing level of class 2, which is denoted as K. Otherwise, class 2 demands are backordered. Backorders are cleared according to the priority clearing mechanism. That is, when a replenishment order arrives, it is first used to clear class 1 backorders then inventory level is increased up to K and at this level, the remaining replenishment quantity is used to clear class 2 backorders. The inventory level can be increased above K only after clearing all class 2 backorders. We show that if such an inventory system is sampled at multiples of supply leadtime, the state of the system evolves according to a Markov chain. We provide a recursive procedure to generate the transition probabilities of this embedded chain. Although the embedded Markov chain has an infinite state space, it is possible to obtain the steady-state probabilities of interest with desired accuracy by considering a truncated version of the chain. The obtained probabilities are also the steady-state probabilities of the original continuous-time system and permit the computation of any long-run performance measure of interest.

Keywords: *inventory, rationing, customer classification, embedded Markov chain, infinite state Markov chain*

A New Allocation Policy for Divergent Multi-Echelon Inventory Systems

Ton de Kok

School of Industrial Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands

In this presentation we discuss a periodic review multi-echelon inventory system consisting of one warehouse and multiple retailers under compound Poisson demand. Under linear holding and penalty costs the optimal policy is an echelon order-up-to-policy, provided that we allow for negative allocations. Several simulation studies have shown that this relaxation has little impact on cost and service performance for systems with identical retailers and demand per period with a low coefficient of variation. However, when the coefficient of variation of demand per period at the retailers gets high, negative allocations occur frequently. Modification rules that ensure non-negative allocations under the echelon order-up-to-policy that is optimal for the relaxed problem, yields a policy that may be far from optimal and for which the analytical expressions for cost and service performance are inaccurate. Typically, the true optimal policy holds more inventory at the warehouse than the optimal policy for the relaxed problem. We use this finding to propose a new allocation that explicitly addresses the imbalance problem by reducing the coefficient of variation of demand satisfied by the retailers. Towards this end we propose a break-quantity policy at the retailers that transfers customer orders exceeding the break-quantity to the warehouse. These customer orders incur a delay equal to the sum of the time until the warehouse can satisfy this demand and ship it to the retailer, and the lead time between warehouse and retailer. Under given break-quantities at the retailers we again relax the constraint that allocations at the warehouse must be non-negative, which allows us to derive the optimal policy for this system. We show that the break-quantities reduce the coefficient of variation at the retailers such that the analytical expressions for the cost and service performance are accurate. We compare the cost performance of the policy proposed against the performance of the policy without break-quantities, modified for negative allocations.

Dynamization of the Trust Game: An Inventory Control Approach

Imre Dobos, Andrea Gelei

Corvinus University of Budapest, Faculty of Business Administration, Department of Logistics and Supply Chain Management, Budapest, Hungary

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The aim of the paper is to model trust and trustworthiness in supply chain relations. In order to achieve this we develop a dynamic version of the classic trust game (Berg et al., 1995). There are a few types of this dynamization (Greiner et al., 2012), but none of them differentiate trust from the concept of trustworthiness that makes the inventory control possible to apply.

Research on trust has a long standing tradition in business research and is generally interpreted as the credibility and benevolence of the trustee perceived by the trustor (Ganesan, 1994; Kumar, 1996). But there is a different approach to trust in the literature as well. This makes a clear distinction between trust and trustworthiness (Mayer et al.; 1995). It stresses that the above introduced concept is a characteristic of the trustee; so it is about the trustworthiness of the trustee and not trust itself. Trustworthiness is a perception; a perception of one actor, the trustor's about a key feature of the trustee's. Trust itself is a closely related but conceptually different term. It indicates the trustor's intentions in risky situations with the trustee. Trust in this case is interpreted as the trustor's willingness to engage in risky behavior with a counterpart in a specific relationship and a specific situation.

Based on this distinction we design an extended dynamic trust game incorporating both concepts, trust and trustworthiness. Trustworthiness in this interpretation is a stock that accumulates resulting from non-opportunistic behavior in risky situations. High inventory level of trustworthiness in relationship results in action based trust.

To analyze the above phenomena we develop a repeated two person game, and present the analytical patterns of behaviors of the players in our model.

Keywords: *trust game, trustworthiness, repeated game, inventory control*

Acknowledgement: *The project is supported by OTKA (K 108 555)*

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An Inventory Control Model for Modal Split Transport: A Tailored Base-Surge Approach

Chuanwen Dong, Sandra Transchel, Kai Hoberg

Kuehne Logistics University, Hamburg, Germany

Firms are increasingly interested in transport policies that enable a shift in cargo volumes from fast transport modes (e.g., trucks) to slow transport modes (e.g., trains or barges). While slow modes are, in general, cheaper than fast modes, they lack flexibility in terms of shipment quantity and delivery frequency. This may cause unnecessary inventories and lost sales. To guide the strategic volume allocation we examine a Modal Split Transport (MST) policy of two modes that integrates inventory controls. While slow-mode deliveries can only be used every other period with a volume that has to be fixed for a long-term horizon, e.g., a year, fast mode deliveries can be used every period and are flexible in the volume. The objective is to minimize the long-run expected total costs of transport, inventory holding, and backlogging. The MST model has a generalized mathematical structure compared to that of the Tailored Base-Surge (TBS) policy in the dual sourcing literature.

We solve approximate problems analytically and provide practitioners an easy-to-implement solution tool. The results provide structural insights on the tradeoff between transport cost savings and holding cost spending and reveal a high utilization of the slow mode. Numerical results indicate that as much as 85% of the expected volume should be split into the slow mode. The numerical tests also show that our approximation is reasonably accurate, with an error of less than 3% compared to the optimal results.

Keywords: *inventory, modal split transport, stochastic model applications, dual sourcing, Tailored Base-Surge policy*

Incorporating Parcel Transportation Costs into Lot Sizing Decisions

Matthew J. Drake, Adam Wenger

Palumbo-Donahue School of Business, Duquesne University, Pittsburgh, Pennsylvania, USA

Objectives of Study: The original economic order quantity (EOQ) model for determining lot sizes was published by Ford Harris in 1913. For the past century, researchers have created and studied variants of the model, spanning almost every possible field and business scenario. One consideration that has been left relatively untouched has been the inclusion of parcel transportation costs into the lot sizing decision. When a business needs to transport products in batches weighing less than 150 pounds, they usually turn to either FedEx, UPS, or DHL. The cost of a parcel shipment is dependent on its origin and destination (categorized into one of seven zones) and the weight of the shipment. When the ordering cost changes relative to the size of the order quantity, we must extend the original EOQ model to account for this variation. Using 2016 parcel rate tables for FedEx and UPS, we developed a variant of the EOQ model that accounts for the quantity-dependent parcel shipment cost. Examination of the parcel rate tables for the two carriers shows that the rates are not linear with respect to the shipment weight. We have developed linear approximations for these rates and have examined the performance of this approximate model compared to the cost of the global optimal order quantity. We have also extended the model to consider the new dimensional pricing based on the volume of the shipment that parcel carriers have introduced in recent years.

Materials and Methods: We used the 2016 parcel rate tables for FedEx and UPS to develop regression models for the rates as a function of the shipment weight. We also used traditional, calculus-based optimization methods to determine the optimal order quantity for the linear approximation model. We conducted several numerical experiments to examine the performance of the approximation model.

Results: Based on the numerical experiments, the linear approximation model performs very well in many circumstances, but there are several situations where it produces a significantly higher cost than the global optimal solution.

Conclusions: Companies can significantly improve their lot sizing decisions by considering the dynamics of the prices evident in the parcel carriers' rate tables. While the rates are non-linear with respect to the weight of the shipment, a linear approximation of the shipment cost produces good results in many cases.

Keywords: *parcel transportation; EOQ; lot sizing; inventory management; dimensional pricing*

A Scenario-based Inventory Optimization Approach for a Multi-Echelon Network

Mehdi Firoozi[1,2], M.Z. Babai[1], W. Klibi[1,3], Y. Ducq[1]

[1] *Kedge Business School, Talence, France*

[2] *IMS, University of Bordeaux, Bordeaux, France*

[3] *Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT), Canada*

Nowadays, Companies have to deal with an uncertain demand which is more difficult to handle when it has a non-stationary pattern. Robust sourcing strategies are necessary for supply chain managers to deal with uncertainties in both supply and demand. Simultaneous decrease of service levels and increase of inventory costs are the most significant impacts of such uncertainties. To deal with this issue, inventory optimization models must be adapted to cover a multi-echelon network structure and to consider alternative sourcing strategies such as lateral transshipment and multiple sourcing. In this paper, a scenario-based modeling approach is proposed to solve a capacitated multi-echelon inventory optimization problem considering a non-stationary demand. The model minimizes the total operational cost that is composed of inventory holding, transportation and backordering costs. Lateral transshipment is applied to reduce inventory backorders. Another important factor in inventory optimization is flexibility. Sourcing from multiple distribution centers is a strategy to reduce supply disruption risk and to cover the possible shortage. Multiple-sourcing is considered in this research and has been analyzed in different scenarios. In order to deal with uncertainties, several scenario samples are generated by Monte Carlo and corresponding sample average approximations programs are solved to obtain the adequate response policy to the inventory system. Extensive numerical experiments are conducted and the results enable insights to be gained into the impact of disruptions on the network total cost and service level.

Keywords: *multi-echelon inventory optimization; uncertainty; lateral transshipment; multiple sourcing; scenario based modeling*

How does Wholesale Price Depend on Initial Inventory at Retailer?

Yigal Gerchak

Department of Industrial Engineering, Tel-Aviv University, Tel-Aviv, Israel

In a decentralized supply chain, the presence of initial inventory at the retailer is believed to cause the manufacturer to set a lower wholesale price than otherwise.

But is such always the case? The importance of that question also derives from a multi-period setting where the manufacturer chooses a wholesale price in each period based on initial inventory at retailer. As the wholesale price is decreasing in inventory level, goes the argument, the retailer will "overstock", referred to as holding "strategic inventory". We show that the optimal wholesale price may increase in initial inventory.

We initially assume fixed retail price, and later consider a model with price-sensitive demand.

We then outline other price-sensitive models based on different demand functions.

Keywords: *initial inventory; uncertain demand; pricing; strategic inventory; decentralized chain*

A Variational Approach to the General Dynamic Lotsizing Problem in Continuous Time

Robert W. Grubbström

Linköping Institute of Technology, Linköping, Sweden

Mediterranean Institute for Advanced Studies, Šempeter Pri Gorici, Slovenia

The *Dynamic Lotsizing Problem*, originally formulated by Harvey M. Wagner and Thomson M. Whitin (1958), considers determining the optimal size of batch quantities over time. This is a generalisation of the Economic Order Quantity Problem addressed by Ford Whitman Harris (1913).

From the original single-product formulation with requirements as discrete time events, assuming no shortages permitted and instantaneous replenishments, through the years developments have been made relaxing several restrictions to include backordering opportunities, allowing a finite production rate, multiple-product dependant demand in assembly systems, and several other lines of extension (Andriolo, et al. 2014, Grubbström 2014A, 2014B, Grubbström et al. 2010).

Simultaneously the objective function has been generalised from the original Average Cost to the Net Present Value (NPV), from Hadley (1964) and onwards.

In the current paper, we continue these considerations treating the single-product case when demand varies over time continuously and/or in discrete impulses, applying the *Calculus of Variations* and the NPV principle to formulate and solve the problem.

***Keywords**: dynamic lotsizing, NPV, economic order quantity, EOQ, calculus of variations*

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Optimizing the Speed of Production vs. the Speed of Repairing in JIT Environment

Zsuzsanna Hauck

University of Pécs, Pécs, Hungary

We consider a manufacturer in Just-In-Time environment. Quality of each product is checked throughout the whole production process, and employees are empowered to signal all quality problems they detect. These problems might be solved during the cycle time of the particular part of the process where defection was found or go through the assembly line to be sent to the problem fixing area.

The company sells good quality products only, and it aims to satisfy all demand. Although, shortages may occur due to slow production, high proportion of defections and/or slow repairing. We consider the speed of production and repairing to be decision variables and optimize their value, considering costs of speeding them up and inventory-related costs (setup, holding and backlogging costs).

Decision on enhancing the speed of production or repairing depends on proportions of speed and speeding cost of these two, and the proportion of unit holding and backlogging costs. Numerical examples will be provided as illustration.

Keywords: *production speed, repairing speed, quality, backlog, optimization*

Emergency Orders in the Periodic-Review Inventory System with Fixed Ordering Costs and Stochastic Lead Times for Normal Orders

Søren Glud Johansen

Department of Mathematics, Aarhus University, Aarhus C, Denmark

This paper presents and specifies the average cost per unit time of various periodic review policies for inventory control of a single item facing compound Poisson demand. Emergency orders are controlled by a reorder point policy with a target stock level, whereas normal orders are issued according to a reorder point policy with a fixed order quantity. We assume that emergency orders have a short constant lead time l and are more expensive than normal orders for which the extra lead time is specified as a stochastic multiple of the review period. In addition to variable and fixed costs for emergency and normal orders, our model includes linear holding and backorder costs.

We investigate three pure policies (PP1, PP2 and PP3) to be used for benchmarking and initialization purposes of two combined policies which allow at most one normal order with remaining lead time longer than l. PP1 and PP2 are the optimal policies when the inventory system is operated without any restrictions by issuing only emergency orders and only normal orders, respectively, whereas PP3 is the optimal policy when the normal orders are restricted to have the same size. The two combined policies are computed by applying Markov decision models. The first policy (OPT) allows the policy variables for emergency orders to depend on the number of review periods since an outstanding normal order (if any) was issued, whereas this dependence is not allowed by the second policy (SIMP). OPT is found by solving a slightly modified version of the rapid policy-iteration algorithm described in Johansen and Thorstenson (IJPE 157, 2014). SIMP is based on neighborhood search of the two policy variables for emergency orders and the order size for normal orders. For each investigated triple of these exogenous variables, the recommended reorder point for normal order and the average cost per unit time are computed by a tailor-made policy-iteration algorithm.

Keywords: *backordering; Emergency order; Markov decision model; policy iteration; reorder-point policy; stochastic lead times*

An Inventory Model with Random Yield and Fixed Ordering Cost

Gudrun P. Kiesmüller, K. Inderfurth

Faculty of Economics and Management, Otto-von-Guericke-University Magdeburg, Magdeburg, Germany

We consider a single stockpoint for a single item subject to stochastic demand and random yield. The system is controlled periodically and each order incurs a fixed replenishment cost. Additionally, linear holding and backorder cost are charged at the end of each period. in contrast to many other studies, we allow a positive leadtime. Since the optimal policy structure for such a system is not known and expected to be very complicated, we assume a periodic (*s, S*) policy with order inflation, where the review period is, without loss of generality, assumed to be one. Thus, an order is placed at a review instant if the inventory position is above thereorder level *s*. The difference between the critical level *S* and the actual value of the inventory position is inflated by the reciprocal of the average yield rate to obtain the order quantity.

In this study we show, that existing approaches to determine the policy parameters can have a very bad cost performance, since they exclude yield uncertainty and rely on the assumption of at most one outstanding order. Therefore, we present three new approaches to obtain near optimal parameters. The first one is based on a continuous time model and extends an existing method including the uncertainty of the outstanding orders. The second approach is based on a steady state analysis and adapts the parameters of an (*R, S*) policy while the last approach uses results from renewal theory to obtain an analytical expression for the cost function. Then, the optimal policy parameters can be computed numerically. All proposed approaches are tested in a numerical study and it can be shown, that the new methods have a good or excellent performance, mainly dependent on the computational effort. Therefore, our new methods overcome the problem to underestimate the necessary safety stock in case of random demand and yield.

Keywords: *stochastic inventory model, random yield, positive lead time, parameter optimization*

Exact Analysis of Lost Sales Base Stock Inventory Systems with Compound Poisson Demand

Chaaben Kouki[1], M.Zied Babai[2], Zied Jemai[3], Stefan Minner[4]

[1] *Essca School of Management, Angers, France*

[2] *Kedge Business School, Bordeaux, France*

[3] *Ecole Centrale Paris, Chatenay-Malabry, France*

[4] *Technische Universität München TUM School of Management, Munich, Germany*

The base-stock policy under the lost sales assumption has been extensively studied in the inventory literature. However, the optimal policy parameter has only been determined under restrictive demand distribution assumptions. In this paper, we extend an earlier research by providing a simple recursive formula to compute the steady-state probabilities of the number of outstanding orders for general compound Poisson demands and general lead times. This enables to numerically compute the exact total cost of the base-stock inventory system under complete and partial rejection policies. Through a numerical investigation, we show the outperformance of our proposed approach.

Keywords: *Base-stock, Compound Poisson, Queueing system, Lost sales, Continuous review*

Optimal Delivery of Two Similar Products to N Ordered Customers with Product Preferences

Epaminondas G. Kyriakidis[1], Theodosis D. Dimitrakos[2], Constantinos C. Karamatsoukis[3]

[1] *Department of Statistics, Athens University of Economics and Business, Greece*

[2] *Department of Mathematics, University of the Aegean, Greece*

[3] *Department of Military Sciences, Hellenic Military Academy, Greece*

We study a single vehicle routing problem, in which a vehicle starts its route from a depot loaded with items of two similar but not identical products, which we name product 1 and product 2. The vehicle must deliver the products to N customers according to a predefined sequence. This means that first customer 1 must be serviced, then customer 2 must be serviced and so on. The vehicle has finite capacity and after servicing all customers it returns to the depot. It is assumed that each customer prefers either product 1 or product 2 with known probabilities. The actual preference of each customer becomes known when the vehicle visits the customer. It is assumed that the number of items that each customer demands is a discrete random variable with known distribution. The actual demand is revealed upon the vehicle's arrival at customer's site. The demand of each customer cannot exceed the vehicle capacity and the vehicle is allowed during its route to return to the depot to restock with items of both products. The travel costs between consecutive customers and the travel costs between the customers and the depot are known. If there is shortage for the desired product it is permitted to deliver the other product at a reduced price. The objective is to find the optimal routing strategy, i.e. the routing strategy that minimizes the total expected cost among all possible routing strategies.

The vehicle routing problem is solved by implementing a suitable dynamic programming algorithm. When the vehicle visits customer j for the first time it satisfies as much demand as possible. We define z(i), i=1,2, as the load of product i carried by the vehicle after the first visit at customer's j site. A negative value of z(i) denotes the unsatisfied demand for product i. It is possible to present suitable dynamic programming equations for the minimum expected future cost (as a function of z(1) and z(2)) from the first visit at customer's j site until the end of the route.

The dynamic programming equations enable us to prove that the optimal routing strategy has a specific threshold-type structure. This structural property leads us to the construction of a special-purpose dynamic programming algorithm that operates only over the routing strategies having this structure. Extensive numerical results provide strong evidence that the special-purpose dynamic programming equation is considerable faster than the original one.

Keywords: *Vehicle Routing Problem, Stochastic demands, two similar products, dynamic programming*

A Heuristic for Computing a New Value-Based Stationary Policy for the Stochastic Joint Replenishment Problem

Christian Larsen

CORAL, Department of Economics and Business, Aarhus University, Aarhus V, Denmark

A stationary control policy is constructed for the multi-item stochastic joint replenishment problem. The cornerstone in the construction is a policy iteration improvement step assuming that there is a single possibility for making a joint order and thus deviate from the rule that the items are governed by independent, re-order and order-up-to, *(s,S)* policies. However this policy iteration improvement step is done repeatedly at each demand epoch. For the policy iteration step it is only required the development of one-dimensional functions of state variables. Knowledge about good order-op-to values is important. So in order to secure that these order-up-to values are hit, when making a joint order, an allocated order cost is constructed for each item. Furthermore, a relaxation parameter α is introduced such that one can, if convenient, make it easier or more difficult to issue a joint order when following the policy iteration step. Also, a vector of can-orders is employed, in case a joint order is made, to include additional items. The policy is denoted a *(c,S,a)* policy. Numerical results show that it perform almost as good as the *Q(s,S)* policy of Nielsen and Larsen (2005), and it moreover, contrary to the *Q(s,S)* policy, is stationary. Also some of the peculiarities of the *Q(s,S)* that can appear for constructed data set, may be better handled by the *(c,S,a)* policy. Numerical results also show that from given a can-order policy one can always construct a better *(c,S,a)* policy.

Comparison of Two Strategies in Multi Supplier Joint Replenishment Problem of Inventory Items with Shortage and Capacity Constraints

Davood Mohammaditabar, Hossein Ghazanfari

Department of Industrial Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran

Objectives of study: Since inventory costs are closely related to suppliers, many models in literature have selected the suppliers and also allocated orders, simultaneously. In practice, ordering multiple items from the same supplier leads to reduction in ordering costs. Some researches in literature studied capacity-constrained supplier selection and order-allocation problem by considering the joint replenishment of inventory items. Two major strategies of direct and indirect grouping are used in the mathematical modelling. In the indirect grouping strategy, replenishment cycle of each item is an integer multiple of a basic cycle time. The problem is to determine the basic cycle time and the replenishment frequencies of all items. But in the direct grouping strategy, items are categorized into groups which will have the same replenishment cycle. Therefore the problem is to determine the grouping of the items and the cycle time of each group. To the best of our knowledge, very few papers have compared the performance of the two strategies in general. Also we didn't find any research which compares the two strategies in multi supplier capacity constrained case.

Materials and Methods: In this paper the mathematical modelling of the two strategies in capacity constrained multi supplier joint replenishment problem with shortage are developed and their assumptions are described. Then the solution process of the models in genetic algorithm (GA) and simulated annealing (SA) is explained.

Results: The performance of the two strategies is compared in a range of numerical examples by using GA and the GAMS software. Statistical test are performed to verify the results. It is shown that directs grouping is performing better for smaller values of the fraction of minor ordering cost to major ordering cost, but in larger values the indirect grouping is performing better.

Conclusions: finally it is discussed that the two strategies have some managerial implication in addition to their mathematical complexities. Therefore the selection of the appropriate strategy is a multi-criteria decision.

Keywords: *supplier selection, Joint replenishment problem, direct grouping, indirect grouping*

A Game Theoretic Model for Capacity Constrained Supplier Selection with Joint Shipment

Davood Mohammaditabar, Atiye Masheli

Department of Industrial Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran

Objectives of study: The supplier selection is a strategic decision-making process of supply chain management. The first models of supplier selection were based on maximizing buyer's interests. Recently, with the growing attention towards supply chains competition and coordination, some researchers propose models that select suppliers based on total supply chain costs.

The joint decision making of procurement lot-size, supplier selection, production quantity and shipment policy selection has potential to reduce whole supply chain costs. It is worth to evaluate whether this joint decision making scenarios are applicable in decentralized supply chains through the use of game theory.

Materials and Methods: In this paper, a two level supply chain of a single-buyer and multi-supplier is considered. The selected suppliers' setup time is integer multipliers of the replenishment cycle time of the buyer. Also suppliers are able to sell their remaining products with a constant rate to the market. A cooperative game theory approach is utilized to evaluate the decisions. In this regard, the selected suppliers, allocated orders and total supply chain costs are determined.

Results: the mathematical model of the problem is developed and the equilibrium point of the game is discussed. Some propositions about the core space and subadditivity of the game are presented. Then some numerical examples are solved and explained to clarify the findings.

Conclusions: It is shown that the cooperative model could result in a stable solution with same total supply chain cost as the centralized model and also, when suppliers have equal opportunity costs for each single production capacity, selected suppliers are determined independent from the opportunity cost. But when the suppliers have different opportunity costs, the selected suppliers are influenced by the opportunity cost that they have. A numerical example describes the findings.

***Keywords**: cooperative game theory, inventory management, joint shipment, supplier selection*

Inventory Policies of Delayed Deteriorating Items with Stock Dependent Decreasing Demand and Complete Backlogging

Munirah Abdullahi[1], **Abubakar Musa[2]**, Bashir M. Yakasai[3]

[1] *Kano State Institute of Information Technology, Kura, Kano-Nigeria*

[2] *Department of Mathematics, Kano University of Science and Technology, Wudil, Kano-Nigeria*

[3] *Department of Mathematics, Bayero University, Kano -Nigeria*

Objectives of the Study: The demand for Inventory Items may be constant or stock dependent. In most cases customers are attracted to the items hugely displayed which make them to buy more. The payment for the items may be instantaneous or could be delayed for a certain period of time offered by the supplier. The main objective of this study is to develop an Inventory Model of Delayed deteriorating Items with Stock Dependent Decreasing Demand and Complete Backlogging.

Materials and Methods: The model developed is constructed on the assumption that the deterioration does not commence at the time the items are stocked but rather the deterioration is delayed. The Model allows for backlogging where the demand for items backordered which is stock dependent, is satisfied first when the next replenishment is received and there is decrease in demand due to deterioration in the interval $[T_1,T_2]$. The total Inventory cost which gives the best cycle length was computed using analytical methods. The cost is made up of ordering cost, inventory holding cost, cost of deteriorated items and the total backlogging cost. Numerical examples are developed to determine the best period T that minimized the total inventory cost per unit time. The best periods are in turn used to determine the total costs. The cycle length associated with the least cost is then selected as the optimum cycle length. The sensitivity analysis of the result is carried out in this study so as to determine the extent to which the output of the model developed is influenced or affected by changes in the input parameters. In particular, the sensitivity of the cycle length T, the economic order quantity as well as the total minimum inventory cost, TIC with respect to the following input parameters was carried out: Ordering Cost, Unit Cost, Inventory Carrying Charge, the time the Deterioration sets in and the time the Inventory is completely Depleted.

Results: Various results were obtained using different parameter values and from the results, it was observed that as the rate of deterioration increases, there is the fall in demand whereas the total inventory cost and the cycle length increases. From the result of the sensitivity analysis, it was established that the percentage increase in the ordering cost increases the total inventory cost and the cycle length while the decrease in the ordering cost decreases the total inventory cost and the cycle length.

Conclusions: In this study, a model on the inventory of delayed deteriorating items with stock dependent decreasing demand and backlogging was developed. From the model developed and the result obtained, it is obvious that the stock level reduces due to deterioration and demand; also as the decay rate increases, the cycle length slightly increases which leads to a longer period within which the inventory items would be depleted. The sensitivity analysis of the result was also carried out to investigate the extent to which the output of the model developed is influenced or affected by changes in the input parameters. This study could be extended to consider partial backlogging, exponential decay rate, price discount and so on.

Keywords: *inventory, delayed deterioration, decreasing demand, backlogging, inventory replenishment*

Simple Modeling Techniques for Base-Stock Inventory Systems with State Dependent Demand Rates

Fredrik Olsson

Department of Industrial Management and Logistics, Lund University, Lund, Sweden

Objectives of study: In this paper new modeling techniques for (S-1,S) inventory systems (continuous review base-stock inventory systems) with state dependent demand rates are proposed. Examples of single-location (S-1,S) inventory systems where the demand, experienced by the system, varies due to the state of the system are, e.g., inventory models with partial backorders, inventory models with lost sales, inventory models with perishable items, inventory models with emergency replenishments etc. Models for such inventory systems are in in general hard to solve due to the fact that the Markov property is often lost, and the prevalent tool used in the literature for providing exact solutions for such models is partial differential equations. Instead of using partial differential equations with rather complicated analysis of boundary conditions, we suggest considerably simpler techniques which are based on elementary theory of queueing and renewal processes.

Materials and methods: The methods used in this paper are probability theory and theory concerning inventory control.

Results and conclusions: First, we provide new intuitive modeling techniques for (S-1,S) inventory systems with state dependent demand rates, which are considerably easier than existing ones. Instead of introducing heavy mathematical machinery as PDEs with rather complicated analysis of boundary conditions, which tends to cloud simple features of the model, we suggest alternative approaches which are based on probabilistic arguments concerning renewal processes and queueing theory. Our approaches reveal that it is possible to derive a model which can track the location of the items in the system for general leadtimes. By applying our approach, it is also possible to further generalize the model to incorporate more complicated demand interarrival patterns compared to the standard Poisson demand arrival process.

Keywords: *inventory control, state dependent demand, base-stock policy, cox process, queueing*

A New Production Policy for M/M/s Make-to-Stock System and Its Renewal Analysis

Sinem Özkan, Önder Bulut

Department of Industrial Engineering, Yaşar University, Izmir, Turkey

This study considers a production setting of a single-item, make-to-stock production system with parallel production channels, fixed start-up cost and lost sales. The decision should be addressed for managing such a system is the production control decision that dictates when to start production and how much to produce i.e., how many production channels should be activated. If the decision is to activate new channels, a setup cost is incurred per channel. The literature of the control of make-to-stock queues is extended by considering fixed system costs and multiple servers at the same time. We first develop the dynamic programming formulation of the problem and then characterize the structural properties of the optimal policy via value iteration algorithm. According to the numerical observations, optimal production policy is highly dynamic and does not have systematic behaviour for practical purposes. Hence, new/alternative policies that have well-defined structures and are easier to apply are proposed. The main contribution of this research is to calculate the average cost per unit time for M/M/s make-to-stock queues with fixed costs and lost sales under the proposed policy. It is obtained by conducting a renewal analysis. Finally, we get a very practical tool which calculates the average cost for M/M/s make-to-stock queue with setup costs in milliseconds. This study can be adapted for the systems with different service times such as Erlangian and Phase-type.

Keywords: *fixed/setup cost, inventory/production control, make-to-stock, multiple servers, renewal reward*

Supply Chain Network Design with Strategic Safety Stock Placement Decisions

Matias Schuster[1,2], Stefan Minner[2], Jean-Sébastien Tancrez[1]

[1] *Louvain School of Management, Université Catholique de Louvain, Belgium*

[2] *TUM School of Management, Technische Universität München, Germany*

Companies can achieve important cost savings by considering their supply chain decisions jointly rather than isolated. In this context, a growing research field aims at integrating inventory decisions into the location-allocation problem. Moreover, demand uncertainty is a major concern for companies as it impacts its responsiveness and forces them to store safety stocks.

We consider supply chain networks composed of retailers, facilities (e.g. warehouses, distribution centers) and one production site. We propose a model that simultaneously determines: *(i)* number and location of opened facilities, *(ii)* allocation of flows between facilities and retailers, and *(iii)* inventory decisions related to safety stock placement. The stock placement is formulated as an extension of the guaranteed service model with differentiated service times, where service times are reduced to the decision of keeping safety stocks at facilities or not. The objective minimizes transportation, cycle inventory, ordering, safety stocks and facility opening costs. The resulting model is non-linear, and we reformulate it as a conic quadratic mixed-integer program, which can be solved directly using standard optimization software packages. We extend the model for different cases such as correlated retailer demands, and different groups of customers at retailers.

The goal of this paper is to better understand the impact of safety stock placement in the supply chain strategic design. When safety stocks are only kept at retailers, the lead time is assumed to be the delivery time from the production site to the retailer. Consequently, in some situations (e.g. for large lead times between facilities and retailers, and small production lead times), it might be more advantageous to keep stocks only at retailers. Thus, interesting managerial insights arise from the balance between the aforementioned lead time effect and the risk pooling strategies at facilities, which are also driven by the number of opened facilities. These effects, among others, are analyzed and supported via extensive numerical experiments.

Keywords: *location-inventory; demand uncertainty; safety stock placement; risk pooling; service times*

Inventory Pooling with Environmental Constraints Using Copulas

Lena Silbermayr[1], Werner Jammernegg[1], Peter Kischka[2]

[1] *Department of Information Systems and Operations, Vienna University of Economics and Business, Austria*

[2] *Department of Business Statistics, Friedrich Schiller University Jena, Germany*

Objectives of study: Pooling is a best practice in inventory management for economic objectives. In this paper we investigate whether pooling stays advantageous if in addition to the economic performance also environmental sustainability is considered, i.e. whether pooling could be bad for the environment and what is the resulting trade-off between economic and environmental performance of inventory pooling.

Materials and Methods: Within the newsvendor framework we consider three pooling models – pooling via centralized ordering, transshipments, and centralization including inventory allocation to the retailers with priority allocation - that include environmental constraints covering all manufacturing and logistics operations of the product.

Results: We characterize the optimal policy of the pooling models with emission constraints, make a detailed comparison between the models and compare them to the decentralized (no pooling) case. Using copulas to model the joint distribution of (positive) dependent demands we prove that for our pooling models the profit decreases with increasing demand dependence. Further we prove that, if the environmental constraint is binding, inventory and emissions decrease with increasing demand dependence and pooling harms the environment compared to no pooling. Additionally, we numerically evaluate the impact of copulas and also characterize when the economic and environmental performance of pooling can be balanced.

Conclusions: In this paper, we discuss the trade-off between economic objective and environmental sustainability for inventory pooling through quantitative modeling which is of importance in order to understand sustainable supply chain management more fully.

Keywords: *risk pooling effect, demand dependence, emissions, carbon footprint constraint, environmental performance*

An Integrated Production and Inventory Control Model for a Multi-National Supply Chain under a Delay in Payment Contract

Ata Allah Taleizadeh, Mahsa Noori-daryan

School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran

It is known that managing inventories plays a crucial role in optimizing costs of inventory systems owing to inventories involve the large portion of companies' assets. Therefore, the companies tend to apply the inventory control policies to be able to manage own inventory levels such that not only not to hold the large amount of inventory levels but also satisfy the market demand. Recently, the companies intend to employ some incentive strategies to motivate the order quantities of buyers. In fact, they go to manage their inventory levels by offering some incentive contracts as return, refund, revenue sharing, quantity discount, delay in payment contract, etc.

In this study, a delay in payment contract in a multi-national two-echelon supply chain is applied to survey the optimal decisions of the chain's partners where a vendor and several retailers are composed the partners of the chain. It is assumed that demand depends on the selling price of product and the partners do not face shortage. A Stackelberg game is established between the members where the vendor is leader and the retailers are the followers. The main goal of the investigation is to determine the optimal pricing and ordering decisions of the vendor and the retailers to optimizing the total profit of the chain under this contract. Eventually, a numeric sample is presented to illustrate the pertinence and applicability of the model.

Optimal Stochastic Inventory Control with Periodically Varying Fixed Order Costs

Florian Taube, Stefan Minner

Logistics & SCM, Technical University Munich, School of Management, Munich, Germany

We study a periodic review single-item inventory model under stochastic demand. Every m periods, in the so-called regular order period, we incur lower fixed costs K when ordering than in the periods in-between, the intraperiods, where we incur higher fixed order costs of L. For inventory on hand at the end of any period we incur holding costs of c_H and for unfulfilled demand backorder costs of c_P per unit and period.

The motivation of this setting is based on the retail industry. In order to reduce the complexity of always changing delivery times for store clerks, every store is assigned to a fixed delivery schedule for products, e.g. one delivery per week. This fixed delivery schedule is constructed in such a way that it reduces the fixed costs of order handling in the warehouse and the transport costs over all stores by means of economies of scale. Within a store, however, goods might run out in between two scheduled deliveries and have to be reordered. As these orders will not be optimally synchronized with the orders of other stores, the effects of economies of scale vanish and much higher fixed costs per order occur for the company. The problem setting is likewise applicable for many other settings such as spare parts being supplied to retailers or the general possibility of multiple supply modes (regular versus emergency supply).

For many quite general inventory systems with fixed order costs, the optimality of (s,S) inventory control systems has been proven. However, as fixed costs vary with periods and rise between a regular order period and the first intraperiod, the central assumption of non-increasing fixed costs in these proofs is not given anymore.

We show that the optimal policy is of a more complex type in the regular order period m and reduces to the (s_j,S_j) policy in the intraperiods (with j as an index for the intraperiod). We describe the optimal policy and prove its optimality based on the notion of K-convexity and the optimal ordering behavior in the presence of general continuous cost functions. We show that, although fixed order costs vary, the cost functions of the intraperiods still fulfill L-convexity and thus lead to optimal (s,S) policies. The cost function in the regular order period does not fulfill K-convexity, which leads to the more complex order structure with multiple order areas. We provide examples for the resulting optimal inventory policies in a numerical study.

***Keywords**: proof of optimality, inventory control, K-convexity, varying fixed cost, (s,S) policy*

Inventory Decision and Pricing under Price-Based and Stockout-Based Substitution

Sandra Transchel

Kuehne Logistics University, Department for Logistics, Hamburg, Germany

Visiting a favorite store and finding the preferred product absent is a common frustration for many consumers. The impact can be detrimental for firms who may not only lose current sales from this particular customer, but also perhaps future business opportunities. At the same time customers may decide to buy a substitutable product instead. Such a behavior may diminish the firm's negative impact of stockouts but can increase the pressure to other products. Thus, anticipating stockout-based substitution in inventory decisions is crucial for firms' profitability. Selling prices are a major driver that do not only influence customer choices but also customers' substitution behavior. Therefore, ideally, inventory and pricing decision should be coordinated for the entire assortment.

This paper examines a stylized stochastic single-period inventory model of two vertically differentiated products with price consideration. The demand for the two products arises from individual consumer choices (adopted from a discrete choice model) and an uncertain total market potential. Specifically, customers are heterogeneous by differing in their valuation of quality. They choose the first available product that maximizes their net utility, which is determined by their perceived quality valuation and the selling price.

We contribute to the existing literature in multiple forms: (i) Solving multi-product inventory problems with stockout-based substitution is still challenging. Past literature has shown that even the simplified two-product problem may not be unimodal. We provide novel structural properties and closed form expressions for optimal solution. In particular, we show that the structural form of the optimal inventory levels depends on the price region. (ii) We show that disregarding stockout-based substitution may lead to overstocking and unnecessary stockouts. We identify a revenue and a demand effect that drive these results and show the impact of the optimal selling price on the inventory levels and the overall profitability. (iii) The results further contribute to the assortment planning literature. When customers are willing to substitute products with higher quality in case of an out of stock of a low-quality product, it might be suboptimal to offer the complete assortment. We show that incorporating stockout-based substitution may affect firms' assortments compared to assortment decisions solely made on profit margins.

Keywords: *inventory decision, stockout-based substitution, pricing, choice models*

Investigation of Initial Inventory Levels in a Supply Chain by an Embedded Newsboy Problem

Imre Dobos, Ágnes Wimmer

Corvinus University of Budapest, Institute of Business Economics, Hungary

The paper will investigate a dyadic supply chain with a manufacturer and a retailer. The manufacturer produces a homogenous product and allocates a certain amount of this product, as initial inventory to the retailer. The retailer reports the number of sold products to the manufacturer at the end of a given time period. The payment should be based on the quantity reported by the retailer to the manufacturer.

The problem described above is modeled as an embedded newsboy problem. There are one deterministic variable and three probability functions in the model:

- quantity allocated by the manufacturer to the retailer at the beginning of the period, decision variable,
- quantity sold by the retailer within the period,
- quantity reported by the retailer to the manufacturer, and
- quantity paid by the retailer to the manufacturer at the end of period.

The aim of the paper is to determine an initial inventory level at the retailer allocated by the manufacturer which minimizes the costs of the embedded newsboy problem.

The second part of the paper analyzes a real world application of the constructed model to a book publishing firm and its retailer. We will examine the dependence of quantity paid by the retailer (sales revenue for the manufacturer) on the initial inventory level allocated by the manufacturer to the retailer.

Keywords: *Newsboy problem, optimization, inventory control, dyadic supply chain*

Acknowledgement

One of the authors is supported by OTKA 105888.

On the Inventory-Distribution Problem with Customer Flexibility

Luca Zeppetella, Elisa Gebennini, Andrea Grassi, Bianca Rimini

Department of Sciences and Methods for Engineering, University of Modena and Reggio Emilia, Italia

Objective of the study: The customer flexibility has been identified as a phenomenon occurring during the order enquiry and quotation stage, before a commitment is made. Our intention is to extend this concept to the inventory-distribution process. Specifically, we address a significant source of customer flexibility that is referred as "demand substitution". In this case the customer accepts an alternative variant if its first choice is out of stock, given that a price discount is offered. This is more common in presence of long term contracts, such as "quantity flexibility (QF) contracts" (i.e., contracts covering long-term requirements used when the total quantity required cannot be definitely fixed but can be stated within lower and upper limits.), which generally enhance the possibility of facilitating an effective demand-supply matching. Our objective is to determine how to satisfy the optimal set of customers in each period of the contract horizon in order to maximize the collected profit, according to the available stocks of each product variant and the price discount applied to encourage demand substitution.

Material and methods: We consider a supplier in a "make-to-order" context which holds inventories of alternative variants of different products. Since for each product different variants exist, the QF contract's requirements and limits can be satisfied by considering the whole set of variants available for the very product. Hence, in each period of the contract horizon, a variant can act as a substitute for some other variant that is currently out of stock.

Results: A mathematical optimization model has been developed for determining how to satisfy the optimal set of customers in each period of the contract horizon in order to maximize the collected profit, according to the available stocks of each product variant and the price discount applied to encourage demand substitution. Moreover, an application in a company operating in the plastics industry which produces different variants of customized storage solutions has been provided.

Conclusion: In this work we include demand substitution issues, related to a certain degree of customer flexibility, into the inventory-distribution problem with QF contracts. Thus, in the context under analysis the term "customer flexibility" refers to both the quantity of product and the specific variant that the customer is willing to receive.

Keywords: *inventory, customer flexibility, distribution, demand substitution, quantity flexibility contracts*

Forecasting for Inventories

A New Method to Forecast Intermittent Demand in the Presence of Inventory Obsolescence

M. Zied Babai[1], Yves Dallery[2], Selmen Boubaker[2], Rim Kalai[3]

[1] *Kedge Business School, Talence, France*

[2] *Ecole Centrale Paris, Châtenay-Malabry, France*

[3] *Ecole Nationale d'Ingénieurs de Tunis, Tunis, Tunisia*

Most work in the area of intermittent demand forecasting is based on Croston's estimator. Some modifications of this method have been proposed in the academic literature with the Syntetos and Boylan Approximation (SBA) being the modification that provides the best forecasting and inventory performance. However, all the Croston-type methods update demand sizes and demand intervals only in periods with positive demand so, periods with zero demand do not imply that forecasts are adjusted downwards which leads to some issues in the case of obsolescence. More recently another method, referred to as Teunter-Syntetos-Babai (TSB), has been proposed in which the demand probability is updated instead of the demand interval, doing so in every period. This method has been shown to provide good theoretical and empirical performance in the case of items with linear and sudden obsolescence. However, the TSB method has been shown to be empirically outperformed by the SBA method in some situations, which is due to the update in every period of the demand probability.

In this paper, we propose a new forecasting method that takes the advantages of both the SBA and TSB methods when dealing with the issue of obsolescence. In fact, the new method updates the demand sizes and demand intervals in periods with positive demand but at any time period if the actual demand interval becomes higher than the most recent estimated demand interval (which is likely to happen in the case of obsolescence), the update becomes in every period. The outperformance of the new method is assessed numerically by means of an extensive simulation experiment considering demand series with linear and sudden obsolescence and empirically by using two datasets coming from the military sector and the automotive industry. The results enable insights to be gained into the linkage between demand forecasting and obsolescence.

Keywords: *Intermittent demand, forecasting, inventory obsolescence, empirical performance.*

Non-Parametric Estimation for Intermittent Demand: Theoretical Analysis and Simulation Results

John E. Boylan[1], M. Zied Babai[2]

[1] *Lancaster University, Lancaster, United Kingdom*

[2] *Kedge Business School, Talence, France*

Intermittent demand is characterised by occasional demand arrivals interspersed by time intervals during which no demand occurs. The estimation of the demand distribution of such patterns is a very important and challenging task for forecasting and stock control. In this context, parametric and non-parametric methods have been proposed in the academic literature to deal with the estimation of the cumulative distribution function as well as the percentiles of such demand patterns. With regard to non-parametric methods, three approaches have been discussed in the literature, namely non-overlapping blocks aggregation, overlapping blocks aggregation and bootstrapping. In this paper, we explore some theoretical results on the properties of the bootstrapping method, comparing its performance to aggregation methods. These properties are further analysed by means of a simulation investigation. A sensitivity analysis is developed with regard to the length of the lead-time, the length of the demand history and the demand lumpiness. The results allow insight to be gained on the relative performance of the estimation methods.

Keywords: *Forecasting, intermittence, aggregation, non-parametric, bootstrapping*

Demand Forecasting with Time-Irregular Stock Measurements for Oil, Gas and Chemicals

Rogier Emmen

ORTEC, Zoetermeer, The Netherlands

Demand forecasting in the oil, gas and chemicals industry is everything but straightforward time series forecasting. In these industries stock levels are typically measured with non-fixed time intervals. Because most of the forecasting literature is about forecasting time series with fixed time intervals it is necessary to either adjust existing forecasting techniques such that they are applicable to irregular time series or to convert the stock measurements into a time consistent series. In this presentation we will discuss both approaches; how they work, their (dis)advantages and some results. Besides the time irregularity the approaches address other difficulties such as: a storage has opening times depending on the weekday, demand varies during the day, there are periods in which demand is exceptionally low/high and there are corrupt measurements in the data.

In inventory routing the objective is to minimize the costs of distributing a certain product over a long time horizon, while making sure that no customer experiences a stock out. In order to make sure that no customer experiences a stock out, the vendor should deliver the product in time. The goals of forecasting demand are to determine the latest delivery date and the quantity of the product to deliver. The latest delivery date is the date where the forecast asserts that with 95% (or even 99%) certainty there will be no stock out. The point-prediction is used to determine the expected quantity that can be delivered at the storage. In this presentation we consider a planning window of a single day, that means that routes need to be planned one day in advance. Therefore, we are only interested in short-term forecasts.

One of the time series patterns that is present in the data is seasonality. The seasonality patterns come in several flavours. In the industrial gas industry the demand often depends strongly on the day of the week. In the fuels industry the demand often depends strongly on the month of the year but sometimes also on the day of the week. A time series pattern that is not often observed is the long-term trend. Temperature is an important external factor in the liquefied petroleum gas industry but we will not cover external factors in this presentation. We adjusted well-known forecasting methods like: moving average, single exponential smoothing and seasonal decomposition such that they are applicable to irregular time series. Each of these forecasting methods update their expectations by iterating over each two consecutive measurements. An advantage of using the average usage rate between two consecutive measurements is that it is the most reliable statistic of the true usage rate (of any arbitrary point in the interval). However, if the true usage rate varies much over the day it is a disadvantage to update your forecasting model when two consecutive stock measurements are only covering a small part of the day. Another disadvantage is that the prediction intervals will rely on residuals that do not have a fixed forecast length.

Another approach is to construct a daily usage series from the stock measurements. A series with daily values is more stable than a series that has multiple measurements per day. Another advantage is that the prediction intervals that are produced rely on residuals that do have a

fixed forecast length. However, a disadvantage is that if one of the multiple measurements on a single day is corrupt, it is not possible to construct a correct average usage rate for that day. Either you have the option to treat the complete day as missing (i.e. throwing away all other usage values of that particular day) or you can make up a usage rate (e.g. by interpolation). In case a storage has very few measurements (e.g. one measurement per week), it is important to not update the forecasting model for each day in particular because this will lead to unrealistic parameter values, unrealistic residuals and unrealistic prediction intervals.

It is clear that both approaches have their advantages and disadvantages depending on the data. In the presentation the approaches will be discussed in more detail together with the results obtained from real life data sets. We will be comparing forecast accuracy, prediction intervals and the consequences they have on the inventory planning (e.g. order volume and stock out).

Keywords: *time-irregular forecasting, prediction intervals, daily patterns, seasonality, corrupt measurements*

Development of Forecasting Tool that Determines the Capacity Requirements for Aircraft Maintenance Center

Adel A. Ghobbar[1], Aris A. Syntetos[2], Vincent Daniël van Rooij[3]

[1] *Air Transport System & Operations Professor, Aviation Management Studies, Research & Translation Center Director, Prince Sultan University, Rijadh, Saudi Arabia*

[2] *Cardiff Business School, Cardiff University, Cardiff, United Kingdom*

[3] *Faculty of Aerospace Engineering, Delft University of Technology, Delft, The Netherlands*

Numerous research on forecasting has been done on the field of aircraft maintenance. However most of this research deals with the forecast of spare parts. This research has two main goals. The first is to develop a forecasting tool that enables aviation Services to forecast the expected capacity in the next time period. The second goal is to research if and using which methods this forecast could be generated. Traditional forecasting is a well-known field of forecasting and a lot of research has already been performed in that area. However traditional forecasting has never been applied to a capacity forecasting problem like in this thesis. The data available made this a unique opportunity to research the applicability of traditional forecasting for capacity. The nature of the time series, being lumpy with a lot of zero values, also made this an interesting field of research. The forecasting tool was developed using Visual Basic for Applications (VBA). The tool generate s a capacity forecast for three departments, the 2400 hydraulics department, the 2500 avionics department and the 2550 power generators department. Furthermore the tool outputs two types of time buckets, monthly and quarterly. Forecasts are made on individual part number level. These forecasts will be used by the forecasting tool to generate a forecast for the whole department. By decomposing the problem into parts could increase forecasting accuracy. This actual forecast depends on both the performance measure used for optimizing and the performance measure used for selecting the best forecasting method. Furthermore demand categorization and the combination of different forecasts can aid forecasting. The influence of these methods on the final forecast will be discussed and the best method will be chosen to generate a forecast.

An Investigation on Bootstrapping Forecasting Methods for Intermittent Demands

Marwa Hasni[1], Mohamed Zied Babai[2], Mohamed Salah Aguir[3], Zied Jemai[4]

[1] *Ecole Nationale d'Ingénieurs de Tunis, Tunis, Tunisia*

[2] *Kedge Business School, Talence, France*

[3] *Ecole Nationale d'Ingénieurs de Carthage, Tunis, Tunisia*

Many bootstrapping approaches have been proposed in the literature since the 1970s to deal with non-parametric demand forecasting. Two approaches have been recently developed to deal particularly with intermittent demands, namely: a first approach that samples demand data by using a Markov chain to switch between no demand and demand periods and a second approach that samples separately demand intervals and demand sizes. The relevant studies claimed improvements in estimating the lead-time demand distribution and the inventory performance achieved over parametric approaches. However, it should be noted that the outperformance of the two bootstrapping approaches has been shown under some restrictive settings and assumptions. The purpose of this paper is to broaden the empirical and numerical settings when analysing the performance of the two bootstrapping approaches. Hence, more realistic assumptions (i.e. demand distributions) and a wider range of control parameters (i.e. length of demand histories, length of lead-times, demand distribution parameters and cost parameters) are considered in the numerical analysis. More empirical datasets with a wider range of demand patterns are also used to validate the numerical findings. The results show that, when long demand histories are considered, the approach based on separate bootstrapping of demand intervals and sizes outperform the other approaches, mainly for long lead-times and for series with small demand variability. The parametric approach shows better performance than the latter approach for highly intermittent demand series and small values of lead-times. However, when short demand histories are considered, the Markov chain based bootstrapping approach leads to the highest performance.

Keywords: *intermittent demand, inventory performance, parametric forecasting, bootstraping*

On the Calculation of Safety Stocks when Demand is Forecasted

Dennis Prak[1], Ruud Teunter[1], Aris A. Syntetos[2]

[1] *Department of Operations, University of Groningen, The Netherlands*

[2] *Cardiff Business School, Cardiff University, United Kingdom*

The inventory control literature generally assumes that the demand distribution and all its parameters are known. In practical applications it is often suggested to estimate the demand variance either directly or based on the one-period ahead forecast errors. The variance of the lead time demand, essential for safety stock calculations, is then obtained by multiplying the estimated per-period demand variance by the length of the lead time. However, this is flawed, since forecast errors for different periods of the lead time are positively correlated, even if the demand process itself does not show (process) auto-correlation. As a result these traditional procedures result in safety stocks that are too low. This paper presents corrected lead time demand variance expressions and reorder levels for inventory systems with a constant lead time where demand fluctuates around a constant level. Firstly, we derive the exact lead time forecast error of mean demand conditional on the true demand variance. Secondly, we derive for normally distributed demand the correct reorder level under uncertainty of both the demand mean and variance. We show how the results can be implemented in inventory models, and particularly discuss batch ordering policies combined with moving average and exponential smoothing forecasts. We find that traditional approaches can lead to safety stocks that are up to 30% too low and service levels that are up to 10% below the target.

Incorporating Macro-Economic Leading Indicators in Inventory Management

Yves Sagaert[1], Stijn De Vuyst[1], Nikolaos Kourentzes[2], El-Houssaine Aghezzaf[1], Bram Desmet[3]

[1] *Ghent University, Ghent, Belgium*

[2] *Lancaster University Management School, Lancaster, United Kingdom*

[3] *Solventure, Antwerpen, Belgium*

Replenishment orders for inventory control require forecasts of future demand, as the lead time after placing an order to the supplier can be substantial. To cope with demand and lead time uncertainty, sufficient safety stock is built on site, considering the appropriate service level. Demand forecasts are typically built using past univariate information, for example of monthly historical sales, sometimes adjusted by human experts. Human experts attempt to introduce information available from the sales team and market environment and dynamics. However, human experts are inconsistent. We propose that market dynamics can be modeled by incorporating leading economic information, and therefore improve the forecasts. Crucially, macro-economic dynamics cannot be observed on the level of a single stock keeping unit (SKU), due to the level of noise and they need to be reviewed on higher levels of aggregation.

In this paper, we build forecasts that make use of macro-economic indicators on a higher tactical level, which are in turn used to augment predictions at the SKU level, where inventory decisions are taken. We investigate whether enriching the predictions with such information results in improved inventory performance. Obviously there are two elements of interest in inventory management: more accurate predictions of the expected future demand; and reduced demand uncertainty, as captured by the prediction intervals. These two quantities are the necessary inputs for safety stock calculations and are the focus of our research.

We evaluate our approach empirically on real-life data from a business-to-business company in the tire production. The inventory decisions are made on the material group level, with a fixed Make-To-Stock order policy. We evaluate and compare the performance of the current forecasts against the proposed forecasts based on leading macro-economic indicators in terms of forecast accuracy and inventory performance.

Keywords: *forecasting, leading indicators, safety stock, inventory, prediction intervals*

Estimating Demand Uncertainty

On the Shelf and the Price is Right: Demand Models for Combined Pricing and Ordering Decisions

Johannes Fichtinger, Emel Arikan

WU Vienna, Department of Information Systems and Operations, Vienna, Austria

Dynamic pricing models continue to be one of the innovations in retail pricing, and the future research opportunities within this field include factors affecting the success of the new models. Both dynamic pricing and revenue management models suggest changing prices based on various factors including the inventory level.

When pricing decisions are made without considering inventory availability, stock-out situations from stochastic demand are not considered; and the focus is on estimating price sensitivity of demand. Uncertainty in demand is not relevant for the pricing model as the profit implications of positive and negative random deviations from mean demand cancel out. Integrating inventory decisions with pricing introduces asymmetric profit implications of random demand: a higher than expected demand realization might cause lost sales while lower than expected demand will result in excess inventory holding (or obsolescence) cost. As these cost are typically different, the effects of demand perturbations on profit do not any longer cancel out. As a consequence demand stochasticity has to be integrated in the demand model.

The most common demand models are additive and multiplicative models, where demand uncertainty – often represented as forecast error – is integrated by an additive or multiplicative term. Both models imply different structural results which follow from variance being constant (decreasing) in price, while the coefficient of variation is increasing (constant) in price for the additive (multiplicative) models.

In this paper, we introduce a demand functional using explicit price dependent functions for mean and variance, which can capture different functional forms of demand uncertainty. Unlike the traditional models, our approach allows estimating the mean model independently from the variance model. In particular, we assume a multiplicative heteroskedasticity model for the variance. Using an exponential term we guarantee the non-negativity of the error variance. The variance function estimation is performed by using a standard procedure described, e.g., by Verbeek (2008).

Using empirical data we analyse the performance of the suggested model, and compare it with the pure additive and multiplicative models. Finally, we are able to report significant improvements on expected profit.

Keywords: *pricing, inventory, demand modeling, newsvendor*

Demand Forecasting by Temporal Aggregation: Using an Optimal or Multiple Aggregation Levels?

Devon Barrow[1], **Nikolaos Kourentzes[2]**, Bahman Rostami Tabar[1]

[1] *Coventry University, Coventry, United Kingdom*

[2] *Lancaster University, Lancaster, United Kingdom*

Recent advances have demonstrated the benefits of temporal aggregation for demand forecasting, including increased accuracy and reduced modelling uncertainty. By using temporal aggregation a time series is transformed, strengthening or attenuating different elements and thereby enabling identification of forecasting models that better fit the time series structure. In the literature two different schools of thought have emerged. The first is primarily focused on identifying a single optimal temporal aggregation level at which a forecasting model maximises its accuracy. In contrast, the second approach fits multiple models at multiple levels, each capable of capturing a different feature of the time series. Naturally these approaches have their advantages and disadvantages, and so far they have only been investigated in isolation. In this study we compare and contrast both approaches from a theoretical and an empirical perspective, discussing the merits of each, comparing the realised accuracy gains under different experimental setups, as well as the implications for the forecasting process. Ultimately we provide suggestions when to use each for maximising demand forecasting gains.

Keywords: *forecasting; temporal aggregation; model selection; exponential smoothing; MAPA*

Combining Forecasts Across Different Selection Criteria

Devon Barrow[1], Nikolaos Kourentzes[2], Fotios Petropolous[3]

[1] *Coventry University, Coventry, United Kingdom*

[2] *Lancaster University, Lancaster, United Kingdom*

[3] *Cardiff University, Cardiff, Wales*

Nearly 50 years of research has focused on forecast combination versus selection. From the one hand findings suggest that correct identification of the 'best' model for a given series may lead to significant accuracy improvements in some cases up to 20-30%. Selecting the best method is challenging in two ways: identifying the best method given sampling uncertainties; and selecting the appropriate criteria. For example, selecting an optimal model based on Akaike Information Criterion (AIC) and Bayesian Information Criteria (BIC) can yield different results. These challenges suggest that there are potential benefits from combining forecasts of models instead. While simple combinations across all available methods may not always be an ideal strategy, combinations performed across a set of suitable methods or using appropriate combination weights usually outperform the selection of a single model. Prior research has focused mainly on combining forecasts of different models, parameters or fitting samples e.g. through bootstrapping. In contrast here we propose a new way to construct pools of forecasts to be combined by combining across different criteria of 'optimal' models. Our approach combines forecasts selected by different selection methods including, Akaike, Bayesian, Hanan Quin information criteria and cross-validation. We benchmark this strategy against the combination from a single model selection criterion and evaluate the forecasting performance of the two approaches under different experimental setups providing recommendations for practice.

Keywords: *forecast combination; model selection; information criteria; cross-validation*

Robust Capacity Planning Under Service Constraints — The M/G/1 Case

Hussein Naseraldin[1], Opher Baron[2]

[1] *Department of Industrial Engineering and Management ORT Braude College, Karmiel, Israel*

[2] *Rotman School of Management, University of Toronto, Toronto, Canada*

Robust planning decisions can be either strategic in nature or operational. If the maximal capacity is sought, then that decision, called provisional capacity, is in fact a strategic decision. If the per-period capacity is sought, then that decision, called operational capacity, is taken in each period. The first is determined at the beginning of the horizon and its value constrains the performance of the system in each period. In this paper, we analyze a multi period setting in which the arrival rate for requiring service is uncertain and waiting-time service constraints are in place. Typically, one searches for a feasible solution that is at least as good as all other feasible solutions for most data realizations. Such an approach is termed Robust Optimization (RO). For example, a health-care clinic may be designed to serve a specific customer arrival rate; but it is plausible that the arrival rate would change over time. If the system is not designed to cope with such uncertainty, public health might be at risk. We model rare arrival rates using the globalized robust optimization (GRO) approach. According to GRO, we find robust solution for realizations that belong to the regular uncertainty set and that solution is partially robust to realizations that belong to the irregular uncertainty set. We consider the problem of capacity planning, both the provisional and the periodical so as to withstand a desired service level (SL). We model the setting at hand under M/M/1 and M/G/1 queues. We focus in this paper on the M/G/1 case. We assume a first-come-first-served rule and that customers wait until served. We further assume that periods between demand changes are long enough such that capacity can be adjusted and the steady state performance are observed by customers during each such period. The cost of varying the capacity in between periods reflects the cost incurred upon short-term changes in the SL and is thus an operational cost. We solve the capacity planning problem to minimize the capacity costs subject to the service constraints. The analytical results show that for small uncertainties, one can safely plan according to the nominal values and best estimates at hand. We also show analytically that the globalized robust solution converges to the robust solution as the irregular uncertainty size shrinks. The numerical study show that while the RO and GRO solutions cost more when designing the system, evaluating their overall cost, including possible realizations from regular and irregular uncertainty sets, may be substantially lower. The effects of costs and length of horizon is also explored and its impact on the price of robustness is investigated.

Estimating Demand Uncertainty over Multi-Period Lead Times

Patrick Saoud, Nikolaos Kourentzes, John E. Boylan

Lancaster Centre for Forecasting, Lancaster University, Lancaster, United Kingdom

Many business context decisions require demand forecasts over a lead time in order to conform to production and delivery requirements. Estimating the variability of lead time demand is crucial in setting safety stocks to hedge against demand uncertainty. Standard inventory literature prescribes the multiplication of the variance of the errors by the lead time and the inverse cumulative distribution function of the normal distribution. This approach however overlooks two correlations that exist within the forecasted demand: the first is a correlation that arises between multiple-steps-ahead forecast errors, and the other between the lead time forecasts themselves. As a result, the safety stock levels reflect poorly the actual quantities required as they underestimate the actual variance of demand. Despite these correlations being flagged up by some authors, no steadfast solution has been offered to overcome this issue, as these correlations can manifest themselves in various forms. In this work we first investigate these correlations from a theoretical standpoint to illustrate the magnitude of uncertainty that is not accounted for. Following that, we propose various empirical approximations to remedy this problem. Although for certain demand processes an analytical correction is feasible to calculate, we provide a solution that is independent of the demand process. This is very relevant for practice, since identifying the true unknown process is not possible and the norm is that the forecasts are produced by a reasonable approximate model. We conclude the work by demonstrating empirically the effect of the proposed correction on meeting the inventory targets.

Asymmetric Prediction Intervals using Half Moments of Distributions

Ivan Svetunkov, Nikolaos Kourentzes

Lancaster Centre for Forecasting, Lancaster University, Lancaster, United Kingdom

Correct prediction intervals are vital for inventory control, as they reflect the risks of going out of stock or storing too much inventory. The conventional method of parametric intervals construction is based on the assumption of symmetry of the error distribution. This assumption often does not hold in practice and the observed forecast errors, and the implied empirical prediction intervals, are non-symmetric and naturally non-Gaussian. This is particularly relevant when events with high impact happen, such as promotions or other disruptions in the supply chain, where skewed error distributions are expected. In this case the deviation from normality makes the conventional method of calculating prediction intervals problematic. Alternative more complicated methods have been proposed, which again do not necessarily guarantee that the correct intervals are constructed. We propose a simple method of constructing prediction intervals based on the half moment of the error distribution. Using this method allows to have both asymmetric intervals in cases of skewed distributions and the conventional symmetric ones in other cases. We conduct an experiment on real data and show the efficiency of the proposed method, and discuss implications for practice.

Inventory Management and Modeling for Perishable Products

Pricing and Advertising in a Supply Chain of Perishable Products Under Asymmetric Information

Tal Avinadav, Tatyana Chernonog

Department of Management, Bar-Ilan University, Ramat-Gan, Israel

We investigate a two-echelon supply chain comprising a manufacturer-leader and a retailer, who are negotiating a wholesale price contract for a perishable product. Product demand depends on retail price, product age, and investment in advertising. The retailer, who is closer to the customers, knows the exact demand function, whereas the manufacturer has only an estimation of this function. We investigate three contracts, in which responsibility for investing in advertising is borne, respectively, by the manufacturer, the retailer, or both. We identify conditions under which the retailer decides to reveal the information at her disposal. We show that product perishability does not affect the retailer's decision regarding whether to share information, but it does affect the operational decisions and profits.

Keywords: *perishable products, asymmetric information, supply chain management, pricing, advertising*

Dynamic Pricing and Dynamic Shelf Life to Reduce (Perishable) Food Waste at Retailers

Marjolein E. Buisman, R. Haijema, J. M. Bloemhof-Ruwaard

Wageningen University, Operations Research and Logistics group, Wageningen, The Netherlands

Approximately 89 billion of tonnes are wasted every year in the EU. Therefore the EU has funded through Horizon 2020 the REFRESH project, which aims to find effective solutions to reduce food waste. In this study the focus is on inventory management at retailers such as supermarkets. A large part of food waste at supermarkets occurs due to consumers who pick products based on expiration dates. To reduce food waste, products close to spoilage can be promoted or expiration dates can be set dynamically. Dynamic pricing, in terms of discounting products close to their spoilage point, is a well-known technique to attract consumers towards buying 'older' products. However, in only a few papers dynamic pricing is studied in combination with dynamic expiration dates. A dynamic shelf life (shelf life that can be adjusted) is possible when changes within the product or in the environment of the product can be tracked. Innovative packaging that is able to detect this, such as and Time-Temperature Indicators is currently available. With these techniques product quality can be determined over time and be used for predicting the remaining shelf life of a product. This lead to a more accurate prediction compared to a fixed shelf life, set by a processor. The two proposed actions are tested with a simulation model that describes a supply chain for a perishable product from the processor to the retailer where products are sold to consumers. The simulation evaluates waste and profit levels at the retailer. Preliminary results show that applying dynamic pricing can decrease waste at the retailers, while profit levels are maintained or increased when the right discount is applied. Dynamic shelf life allows retailers to sell products according to their actual quality and thus reduces the wastage of products that are still of good quality. The combination of dynamic pricing and dynamic shelf life can be even more effective as both are considered to have a beneficial effect on waste reduction.

Keywords: *dynamic shelf life, dynamic pricing, perishable food product, consumer behaviour, food waste reduction*

Optimization of Production-Inventory with Pricing and Promotion Effort for a SVMB-VMI System of Perishable Products under Small Batch Shipment Policy

Zhixiang Chen[1], Bhaba R. Sarker[2]

[1] *Department of Management Science, Sun Yat-sen University, Guangzhou, China*

[2] *Department of Industrial Engineering, Louisiana State University, Baton Rouge, USA*

Objective of Study: The objective of his paper is to investigate the mutual impact of production and marketing decisions and the possibility of integration of production and marketing decision for perishable products, provide practitioners with helpful guideline in implementing JIT production and inventory control for perishable products.

Materials and methods: The case background of this study is consisted of a manufacturer and multiple retailers and a VMI strategy is applied to control the inventory. Pricing, promotion effort and inventory replenishment policy of retailers and production lot size of the manufacturer are taken as decision variables in the model. The special features of the model lie in three facets. First, we propose a new concept in constructing demand function, i.e., BCR (brand competition ration). Second, in order to reduce the inventory of retailers, a small batch policy of JIT philosophy is applied to deliver goods from the manufacturer to retailers and transportation costs between the manufacturer and retailers are included in the total cost. Third, the customer service level of retailers is also considered in the model. Two promotion strategies--retailers bear their own promotion cost and the manufacturer shares promotion cost, are examined to compare the difference of centralized and decentralized models.

Results: We obtain the optimal price and promotion effort level and the inventory replenishment policy for retailers and the production lot size for the manufacturer. Numerical examples are demonstrated to show the application of the model and algorithm. Parameters sensitivity is conducted to analyze the impacts of parameters on the results. Important managerial implications are put forward based on the results.

Conclusions: The model can be extended to consider more other factors, e.g., time-varying demand and deterioration, and retailers' competition behavior.

Keywords: *production-inventory; pricing; promotion effort; perishable products; single-vendor multi-buyer; small batch shipment*

Distribution Network and Inventory Decisions of a Food Aggregator cum Restaurant

Kavitha Chetana Didugu, Chetan Soman

Indian Institute of Management, Ahmedabad, India

The online food service industry is swarmed with a number of players, and with different business models- online ordering, food aggregators, hyperlocal food delivery, etc. These entities, however, have hitherto received little research attention.

This paper attempts to explore the operation of an online hyperlocal food aggregator that functions as a quick service restaurant (QSR) as well. We examine its distribution network decisions at a strategic level, considering its partnering restaurants and customers. The chosen restaurants belong to the same locality/region as the aggregator.

We propose a network design for the system, where the restaurants operate under service area constraints. This means that each registered restaurant is confined to serve a particular customer region. There is demand information sharing between the aggregator and the restaurants. All the restaurants including the aggregator decide how much of each product to produce and how much to outsource to each other.

We formulate a mixed integer programming model to represent the distribution network design in the above scenario. A numerical study is conducted by varying the number of restaurants, the demand functions, the capacity of each facility, the range of products on offer, and the maximum service radius.

This model answers the questions of the viability of the business model described above. It also helps analyse the impact of service area constraints, service level and the number of aggregator's branches on the inventory and capacity decision of each entity in the network.

This paper, to the best of our knowledge, is probably the first attempt at examining the contemporary online food service industry closely. It analyses the aggregator cum QSR business model in detail, exploring the optimal distribution in terms of profit, capacity choice, and service area constraints. It also provides an insight into hyperlocal entities and the difference from the existing aggregator-only model.

In this paper we confine the interaction of the network members to choosing capacities for in-house production facilities and for reserving capacities from the partnering restaurants for each product. Further interactions within the network, such as inter-restaurant product bundling, accommodation of varying operating hours of all the restaurants in the network, etc., need to be explored. Another possible direction for further research is towards lateral transhipments among the restaurants.

Keywords: *distribution network design, online food aggregator, service radius, minimum business guarantee*

Testing Robustness of Deterministic Models of Optimal Pricing and Lot-Sizing Models with Deterioration and Partial Backlogging

Maryam Ghoreishi, Christian Larsen

Cluster for Operations Research and Logistics (CORAL), Department of Economics and Business Economics, Aarhus University, Aarhus, Denmark

Many models within the field of optimal pricing and lot-sizing models with deterioration and partial backlogging assume everything is deterministic and develop a differential equation as the core of analysis. Two prominent examples are the papers by Rajan et al (1992) (Management Science, Vol 38) and Abad (1996) (Management Science, Vol 42). These papers show a remarkable feature namely that that the problem can be decomposed into solving a pricing problem and thereafter solving a lot-sizing problem. To our knowledge nobody has ever tested whether these solutions can be implemented if the real system is exposed to randomness: with regard to demand process as well as with regard to the deterioration process. The motivation is that although the real world is indeed stochastic it is often more convenient to work with deterministic decision model providing nice closed form solution. The crucial thing is of course whether the results derived in the deterministic setting are robust when tested in a stochastic environment. We do our testing in two levels. The first level is numerical test, where we test the robustness of the numerical results reported in Rajan et al (1992) and Abad (1996) in a simulation model. Here our numerical results seem to confirm that the results stated in these papers are indeed robust when being imposed to stochastic inputs. The second level of testing address the more qualitative result namely that we can decompose the pricing and the lot sizing decision. In order to test this we develop a semi Markov decision model built over the model of Rajan et at (1992), that is, without backlogging. We develop a policy iteration algorithm that for a given lot-size finds the optimal pricing policy. We implement this algorithm and investigate numerically whether the lot size and pricing decision can be decomposed.

Keywords: *inventory control, optimal pricing, deterioration, simulation, semi Markov decision model*

Near Optimal Ordering of Perishables

Rene Haijema[1], Stefan Minner[2]

[1] *Wageningen University, Wageningen, The Netherlands*

[2] *Technical University of Munich, Munich, Germany*

Objective*:* The ordering of perishable products in practice is commonly based on base stock policies (BSP), which are traditionally developed for non-perishable products. In the last decade, a number of alternative order policies have been proposed ranging from stock level dependent policies, which neglect the ages of products in stock, to more complicated stock age dependent policies, which takes the ages of the products in stock into account. Recently a modified base stock policy BSPlow is constructed that performs very well by adding parameters that will either smoothing order quantities or allow skipping order moments. In this paper this policy is compared with several stock-age dependent policies, and it is investigated what near optimal parameter values of BSPlow are.

Material and methods: For a large design of experiments, optimal replenishment parameter values are obtained by simulation based optimization. These results can be used to study the structure of near optimal policies and to set near optimal parameters.

Results: Numerical results obtained by simulation show that the policy BSPlow is doing even better than most existing stock-age dependent policies. Based on numerical insights, new stock-age dependent policies are constructed and compared by simulation for a wide range of problem settings. Besides the comparison of policies we address how near optimal parameters can be approximated.

Conclusions*:* A stock level dependent policy may outperform a stock age dependent policy. Adding a waste correcting term may improve the performance of a policy, but requires additional, usually complicated, calculations to be executed at every order moment. For a fast determination of near optimal parameters values, approximations are needed.

Keywords*: order policy, perishable products, food waste, inventory management, simulation based optimization*

Fresh Product Inventory Management in the Wholesale Market

Xiangyu Hou[1], Rene Haijema[2], Dacheng Liu[1]

[1] *Tsinghua University, Beijing, China*

[2] *Wageningen University, Wageningen, The Netherlands*

The fresh product supply chain in China is connected through the wholesale market. Large amounts of wholesalers and retailers get together in the daily market and the product's price is determined by the total supply and demand. The market price and the retailer's demand are related in our model. Under the varying market condition, a wholesaler has to make many decisions such as how many products to sell to a secondary market, how many products to purchase and so on. Based on the reality, this paper models the market process, and optimizes the wholesaler's decision.

The problem is complicated for (1) being a multi-period decision problem for perishable products, (2) stochastic demand depends on quality of displayed products, and (3) market price is not fixed and has an influence on the decision. The wholesaler thus has a balance between two opposite decision tendencies that could increase the profit. One is to enlarge the quality-dependent demand which promotes the profit by increasing the turnover. The other is to reduce the waste and save the cost but results in less demand. The tradeoff between them is the key issue for fresh product inventory management as well as the perishability's influence.

A Markov decision process model is employed to describe the complicated problem with the wholesale market's features. However, the MDP model is not capable for large scale problem, so we use realistic but rescaled (to keep the problem computationally feasible) data sets to study the problem's property and observe the optimal policy. Then we develop easy-to-apply heuristics by learning from the observation. We also design a group of experiments according to different realistic scenarios. Using the experiments, we test the heuristic and analyze the reality in the wholesale market by simulation. It provides the practitioners a clear perspective and a useful policy in the operation. It also helps us have a better understanding on the logic of the wholesale market.

On the Benefits of Emergency Orders in Perishable Inventory Systems

Chaaben Kouki[1], M.Zied Babai[2], Stefan Minner[3]

[1] *Essca School of Management, Angers, France*

[2] *Kedge Business School, Bordeaux, France*

[3] *Technische Universität München TUM School of Management, Munich, Germany*

We consider inventory systems for perishables with two-supply modes. Replenishments arrive at either regular lead-times or emergency ones, characterized by a shorter lead-time but with a higher purchasing cost. These policies use real-time supply information that allow us to derive the steady-state behavior of the inventory systems and obtain the exact optimal expected total cost. We investigate the value of dual-sourcing in the context of perishable items with stochastic lifetime.

Keywords: *perishables, base-stock, dual-sourcing, emergency orders, lost sales*

Inventory Routing Problem for Deteriorating Items Considering Transshipment Option and Accident Risk

Ali Timajchi[1], Y. Rekik[2], **S.M.J. Mirzapour Al-E-Hashem**[1]

[1] *Department of Industrial Engineering, Amirkabir University of Technology, Tehran, Iran*

[2] *EMLYON Business School, Écully, France*

In this study we address an Inventory Routing Problem for deteriorating pharmaceutical items in which environmental considerations are taken into account. The proposed model is a Bi-objective mixed integer mathematical programming one. The first objective aims to minimize the total cost including ordering, transportation, shortage and inventory holding costs. The second objective function attempts to minimize the accident risk. The products deteriorate under a constant deterioration rate during the storage period. Each hospital demand is assumed to be deterministic but time varying over a finite planning horizon. Demand can be provided through a supply network, either from the main supplier, or from other related hospitals' drugstores (Transshipment). For each route, an occurrence probability of accident is taken into account. The model therefore attempts to utilize the best configuration of the routes based on their fuel-efficient and accident risk features to satisfy the demand. Several numerical examples are generated and solved by a standard linear programming solver, CPLEX. The results show that the proposed model be able to make a reasonable tradeoff between the economic and ecological decisions.

Keywords: *inventory routing problem; deteriorating items, transshipment, accident risk*

Fixed Reorder Days for a Perishable Product in Retail

Karin G.J. Pauls-Worm[1], Eligius M.T. Hendrix[2]

[1] *Wageningen University, Operations Research and Logistics Group, Wageningen, The Netherlands*

[2] *Universidad de Málaga, Computer Architecture, Málaga, Spain*

We study retail order policies for a practical situation where stores may be able to order every day, or on fixed days of the week. Focus is on a perishable product which has a remaining shelf life on delivery at the store of three days and a weekly (seasonal) demand pattern which is stationary over the weeks. The stores have a target α-service level, i.e. the inventory should cover demand in more than α % of the days. The customer demand may be First In First Out (FIFO) or a Last In First Out (LIFO) – FIFO combination. A Stochastic Programming (SP) model is presented of the situation in the retailer practice. Four different policies to determine the order quantity are studied. The base is a *YS* order policy where the reorder days *Y* are fixed and order-up-to levels *S* are used, with parameter values generated by an MILP approximation of the SP model. Numerical experiments compare the effectiveness of the policies to determine the order quantities with respect to costs and reached service levels. The first policy determines the order quantity considering the total available inventory. This gives lowest cost solutions, which are not always feasible. From the three other studied policies, the policy where a fraction of the total available inventory is considered when determining the order quantity, performs best. One can always find a fraction that gives feasible solutions.

Keywords: *retail; order policy; perishable product; non-stationary demand; service level constraint*

A Multi-Product Stochastic Inventory Control System for Deteriorating Products

A.A. Taleizadeh, Mahsa Noori-daryan

School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran

While the usual assumptions in multi periodic inventory control problems are that the orders are placed either at the beginning of each period (periodic review) or depending on the inventory level they can happen at any time (continuous review), in this paper we assume the periods between two replenishments of several deteriorating products are identical and independent random variables. Both the deteriorating and demand rates are constant and maximum inventory level (decision variables) are of integer-type. Maximum order quantity, service level, budget and space limitations are constraints of problem on hand. The costs associated with the inventory control system are deteriorating, holding, purchasing, backordering and lost sales costs. Multi product multi constraint situation should be investigated such that the limitations are warehouse, budget, and maximum order quantity and service level for each product. Shortage is permitted and fraction of the unsatisfied demand will be backordered and the remained quantity will be lost. It should be noted that only one supplier exists and all of the purchased products will be sold. Identifying the inventory levels in each cycle such that the expected profit is maximized is the principal objective of this research. The proposed model is an integer nonlinear programming type and to solve it, genetic algorithm is employed. At the end, a numerical example is given to demonstrate the applicability of the proposed methodology.

Keywords: *inventory control; stochastic replenishment; deterioration; integer nonlinear programming; genetic algorithm*

On the Potential to Reduce Food Waste and Increase Sales for Perishables in Supermarkets

Karel van Donselaar, Rob Broekmeulen

Eindhoven University of Technology, Eindhoven, The Netherlands

Purpose: Roughly one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year. The associated costs are estimated to be equal to 856 billion euro's each year. Retailers are faced with the costs and social stigma of waste and look for ways to deal with the trade-off between availability and waste.

This paper is the first to quantify the potential to reduce waste or increase sales for perishables by combining theoretical results with empirical data from three large supermarket chains in Europe. In addition we will provide tools and techniques that can help retailers and their suppliers to better manage the balance between waste and On-Shelf Availability.

Methodology: Empirical data from 81 fresh departments from 27 supermarkets are analysed. These empirical data are combined with recent theoretical results which quantify the relation between waste and on shelf availability, resulting in Efficient Frontiers. These Efficient Frontiers are used to benchmark the fresh departments and to quantify and prioritize several improvement opportunities in the fresh supply chain like extending the shelf life with one day or unpacking the items at the DC. Interviews and a literature review have resulted in a list with improvement suggestions.

Findings: The improvement potential for waste reduction and/or sales increase in practice is shown to be very large. For example, extending shelf lifes with only one day or unpacking case packs at the DC deliver waste reductions well above 30% for the combined dataset with data from the three participating retailers.

The Fresh Case Cover, defined as the case pack size divided by the average demand during the shelf life, is shown to be a good first indicator for the percentage of waste.

The concept of the Efficient Frontier is shown to be an effective way of distinguishing well-performing from less-performing fresh departments.

The analysis of empirical waste data has revealed that current approximations in the literature are based on assumptions which are not always met in practice. Based on this observation a new and more generic approximation has been developed, which is shown to be accurate.

Contribution: This research project has provided several contributions to both theory and practice on waste and sales optimisation for perishable items:

- A new method to benchmark the performance of fresh departments in supermarkets
- A new mathematical approximation for perishable items with high waste
- The introduction of an easy-to-use first indicator for waste, tested with the empical waste data from the participating retailers.
- A list of more than 50 improvement suggestions to increase sales and/or reduce waste in the fresh supply chain

- Empirical validation and quantification of the improvement potential for fresh departments in supermarkets
- To facilitate implementation of theoretical results on waste, existing computer programs are simplified and transformed in a tool which is easy-to-use in practice; the tool can be used to quantify and prioritize improvement initiatives for fresh supply chains.

Keywords: *food waste, retail operations, empirical data*

Dynamic Pricing of Perishable Products in Supermarkets

Yue Wu[1], Jiabin Luo[2]

[1] *Southampton Business School, University of Southampton, Southampton, United Kingdom*

[2] *University of Coventry, Coventry, United Kingdom*

Objectives of study: This paper proposes a dynamic pricing method for a specific type of perishable product, i.e. fresh bakery, in a supermarket. Unlike conventional products, the quality of perishable products changes significantly over the time. We aim to determine the original selling price, discounted price, discounted time and the quantity to produce continuously during the planning period, in order to maximise the profit of the supermarket.

Materials and methods: Customer demand at any time point is described as a function associated with selling price at that time. The store produces the product with a constant unit cost. Any unsatisfied demand will incur a penalty cost. At the end of the planning period, all the unsold products will be disposed at extra cost. The problem is modelled as a non-linear programming model and we have designed a novel genetic algorithm (GA) to solve the considered problem.

Results: The proposed model and algorithm is illustrated by an example of a particular fresh bakery product. Suppose the store opens 12 hours a day and the product will be sold at a discounted price in the last few hours of the opening time. The discounted prices are taken from 20%, 50% and 80% off the original selling price as an example. By solving the model, we find out how the best profit achieved. We also observed that (1) regardless of the starting discounted time, less discount results in a higher profit; (2) to satisfy the customer demand, if the discounted time starts earlier, more products need to be produced each hour; and (3) starting discounted price in the last hour cannot guarantee the best profit because the profit is affected by the demand and also by the original selling price and the amount of products produced. In addition, there are a set of experiments on GA to show its efficient convergence behaviour and the effects of different parameter settings, so as to verify the effectiveness of the proposed algorithm.

Conclusions: This research develops a non-linear deterministic model to solve a pricing problem for one type of perishable products. The designed GA is very efficient in solving this problem and the results can be obtained in a very short time in all the experiments. This work can be extended by considering stochastic demand with applications in multiple perishable products.

Keywords: *dynamic pricing, perishable products, inventory, revenue management, genetic algorithm*

Maintenance & Service Logistics

Fleet Readiness: Stocking Spare Parts and High-Tech Assets

Joachim Arts, Rob Basten

Eindhoven University of Technology, Eindhoven, The Netherlands

We consider a maintenance shop that is responsible for the availability of a fleet of assets, e.g., trains. Unavailability of assets may be due to active maintenance time or unavailability of spare parts. Both spare assets and spare parts may be stocked in order to ensure a certain fleet readiness, which is the probability of having sufficient assets available for the primary process (e.g., running a train schedule) at any given moment. This is different from guaranteeing a certain average availability, as is typically done in the literature on spare parts inventories. We analyze the corresponding system, assuming continuous review and base stock control. We propose an algorithm, based on a marginal analysis approach, to solve the optimization problem of minimizing holding costs for spare assets and spare parts. Since the problem is not item separable, even marginal analysis is time consuming, but we show how to efficiently solve this. Using a numerical experiment, we show that our algorithm generally leads to a solution that is close to optimal, and that it is much faster than an existing algorithm for a closely related problem. We further show that the additional costs that are incurred when the problem of stocking spare assets and spare parts is not solved jointly, can be significant. A key managerial insight is that typically, the number of spare assets to be acquired is very close to a lower bound that is determined only by the active maintenance time on the assets. It is typically not cost effective to acquire more spare assets to cover spare parts unavailability.

Inventory Management with Two Demand Streams: A Maintenance Application

Rob Basten[1], Jennifer K. Ryan[2]

[1] *Operations, Planning, Accounting & Control, Eindhoven University of Technology, Eindhoven, The Netherlands*

[2] *University of Nebraska-Lincoln, Lincoln, USA*

We consider an inventory system facing two types of demands with different priorities and different advance demand information. Such a system arises in multiple contexts, including spare parts inventory management. Spare parts are used in the maintenance of capital assets, both for preventive, planned maintenance, in order to prevent future failures, and for corrective, unplanned maintenance. We propose to jointly control the inventory for these two demand streams. We study a periodic review inventory system with a single stocking point used to meet deterministic, low priority demands, as well as stochastic, high priority demands. We characterize the structure of the optimal policy and demonstrate that the inventory requirements for the stochastic demand stream can be reduced when the inventory for the two streams is jointly managed. We also demonstrate that a myopic policy is optimal when planned maintenance may be delayed at most once. For a general setting in which planned maintenance may be delayed more than once, we formulate a Markov decision process model, which we use to characterize the structural properties of the optimal policy and to develop a number of myopic heuristic policies. Using a set of numerical experiments, we demonstrate that these heuristic policies perform extremely well, and we show that a policy which allows for at most one delay provides a system performance very close to that of a policy that allows for an unlimited number of maintenance delays. This final insight is critical for practical implementation and managerial acceptance of our proposed policy.

Keywords: *inventory, two demand streams, maintenance*

Improving Failures Forecasting in Service Logistics – Using Bayesian Networks to Model a Changing Context

Petros Boutselis[1], Ken McNaught[2]

[1] *Centre for Defence Acquisition, Cranfield Defence and Security, Shrivenham Oxfordshire, United Kingdom*

[2] *Centre for Simulation and Analytics, Cranfield Defence and Security, Shrivenham Oxfordshire, United Kingdom*

Objectives of study: More flexible modelling of a Logistic Support System (LSS) in order to take better account of various contextual factors affecting availability. Materials and Methods: A probabilistic model (a Bayesian network) is developed comprising the LSS-context defining factors such as the number of supported systems, on-hand inventory and repair times. This is built partly through an automated procedure using data usually collected in the field. The discussion is on the evaluation of the ongoing work on the BN development methodology through a case study using data provided from a computer simulation. The simulated system is a three-echelon LSS of generic UAV units, composed of first-line maintenance, second-line spares for repair and a resupply depot.

Results: The anticipated benefit of the suggested methodology is the efficient development of a BN model which in turn provides a flexible way of modelling the effects of contextual factors on availability. The efficiency stems from the fact that the model uses the LSS structure and thus reduces the effort to elicit the context knowledge from the experts. Furthermore, by using data already collected, the required expert elicitation of probability distributions is reduced. Finally, the resulting BN provides a probabilistic expert system that enhances knowledge management within the support organization. Regarding the anticipated effectiveness of the methodology, the BN captures the relationships between the units' failure rates, repair rates and their context defining factors.

Conclusions: The benefits of the methodology can be appreciated when changes in the context defining LSS factors are planned, or when future similar support systems are to be developed. Additionally, the structure of the BN is such that its outputs follow the requirements of related Multi-Indenture Multi-Echelon (MIME) optimization methods like V-METRIC and so it can provide more contextually informed inputs to the latter.

Keywords: *Bayesian networks, failure rates, availability, MIME*

The Role of Contract Expirations in Service Parts Management

Rommert Dekker[1], Cerag Pince[2], Hans Frenk[3]

[1] *Erasmus University Rotterdam, Rotterdam, The Netherlands*

[2] *Kuhne University, Hamburg, Germany*

[3] *Sabanci University, Istanbul, Turkey*

The majority of after-sales service providers manage their service parts inventory by focusing on the availability of service parts. This approach, combined with automatic replenishment systems, leads to reactive inventory control policies where base stock levels are adjusted only after a service contract expires. Consequently, service providers often face excess stock of critical service parts that are difficult to dispose due to their specificity. In this study, we address this problem by developing inventory control policies taking into account contract expirations. Our key idea is to reduce the base stock level of the one-for-one policy before obsolescence (a full or partial drop in demand rate) occurs and let demand take away excess stock. We refer to this policy as the single-adjustment policy. We benchmark the single-adjust-ment policy with the multiple-adjustment policy (allowing multiple base stock adjustments) formulated as a dynamic program and verify that for a wide range of instances the single-adjustment policy is an effective heuristic for the multiple-adjustment policy. We also compare the single-adjustment policy with the world-dependent base stock policy offered by Song and Zipkin (1993) and identify the parameter combinations where both policies yield similar costs. We consider two special cases of the single-adjustment policy where the base stock level is kept fixed or the base stock adjustment is postponed to the contract expiration time. We find that the initial demand rate, contract expiration time, and size of the drop in demand rate are the three key parameters driving the choice between the single-adjustment policy and its special cases.

Optimal Reliability and Commonality - A Service Logistics Perspective

Joni.P.C. Driessen, Joachim J. Arts, Geert-Jan van Houtum

Eindhoven University of Technology, School of Industrial Engineering, Eindhoven, The Netherlands

Introduction: Capital goods are systems characterized by their advanced technology and large capital investments required. Original Equipment Manufacturers (OEMs) of such capital goods provide full service contracts (Oliva and Kallenberg, 2003) or close Performance Based Contracts (Kim et al., 2007) through which the OEM becomes responsible for design, production, and service logistics. Therefore, the OEM is primarily interested in minimizing the life cycle costs (LCC) of its systems. Service logistics costs constitute 75% of these costs (Öner et al., 2007), and refer to all logistic activities during system exploitation, e.g. maintenance and spare part inventories. These service logistics are a pivotal element that should be taken into account in system design, to minimize the LCC, as 70-85% of these costs are determined during system design (Asiedu and Gu, 1998).

The OEM manages multiple system variants that share a common platform. We refer to the number of machines of the same variant as the installed base. The OEM has to decide whether a component should be made common or variant specific (called dedicated component). In addition to the common-dedicated problem, the OEM has to decide how reliable and expensive such components should be. We study this design problem from a service logistics perspective, and prove that there exists a threshold that determines whether commonality implies more or less reliable components. This threshold directly depends on the relationship between reliability and the unit cost of a component. Furthermore, we analytically characterize three regions for the cost of a common component, that show when commonality is an attractive alternative. The regions' boundaries are characterized by the installed base sizes of the dedicated components, and we prove that the more similar the installed bases become, or when the number of dedicated components increases, commonality becomes more attractive.

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Integrated Maintenance and Spare Part Optimization for Moving Assets

Sena A. S. Eruguz, Tarkan Tan, Geert-Jan van Houtum

Eindhoven University of Technology, Eindhoven, The Netherlands

We consider an integrated maintenance and spare part optimization problem for a single critical component of a moving asset for which the degradation level is observable. Degradation is modelled as a function of the current operating mode, mostly dictated by where the moving asset physically is. The spare part is stocked at the home base where the moving asset eventually stops by. Alternatively, the spare part can be stocked on board of the moving asset to prevent costly expedited deliveries. The costs associated with spare part deliveries and part replacements depend on the operating mode. Our objective is to minimize the total expected discounted cost of spare part deliveries, part replacements, and inventory holding over an infinite planning horizon. We formulate the problem as a Markov decision process and characterize the structure of the optimal policy, which is shown to be a bi-threshold policy in each operating mode. Our numerical experiments show that the cost savings obtained by the integrated optimization of spare part inventory and part replacement decisions are significant. We also demonstrate the value of the integrated approach in a case study from the maritime sector.

Keywords: *condition-based maintenance, spare parts, moving assets, inventory, maritime*

Traditional and Reverse Consignment Policies for Critical Service Parts of Complex Equipment

Ivan Ferretti, Laura Mazzoldi, Simone Zanoni, **Lucio E. Zavanella**

Department of Mechanical and Industrial Engineering, University of Brescia, Italy

The main objective of this study is to determine the optimal inventory management policy for critical service parts, based on cost minimization, and considering uncertainty of repair lead times for complex equipment.

A single Vendor-single Buyer system is considered, where the second purchases co-designed complex equipment (e.g. aircraft engines) by the first one. The failure of such equipment is usually due to the failure of one (or more) critical component(s). Because of the Vendor's know-how related to design and manufacturing of considered equipment, maintenance contracts are stipulated between the Buyer and the same Vendor, who is responsible to restore the equipment availability in case of failure. Usually, as the cost for production loss due to equipment failure is very high, relevant penalties are charged to the Vendor in case repair lead times are longer than those defined in the maintenance contract. In particular, repair lead times are subjected to uncertainty, as they mainly depends on inventory management policy of service parts. In particular, their costs (or penalties) are crucial to determine Vendor margins with reference to maintenance fee paid by the Buyer.

The aim of this work is to define an inventory management policy that minimizes supply chain (i.e. Buyer-Vendor) total inventory cost for critical components service parts and, at the same time, that ensures high service level to the Buyer, i.e. high equipment availability.

Two different mathematical models are presented considering (1) a traditional inventory management policy for service parts inventory costs minimization, and (2) a *reverse consignment* inventory management policy that considers critical service parts stored at Vendor's but purchased by the Buyer.

A numerical analysis considering different scenarios is developed, and comparison of results obtained for the two policies show that *reverse consignment* policy outperform the traditional one, in terms of Buyer costs and Vendor profit, that are lower and higher, respectively, in case of *reverse consignment* policy.

As quite literature exists on *reverse consignment* policy, this paper could be extended by involving different aspects that can influence the models behaviour. Contractual issues (i.e. definition of penalties for Vendor) or multi-Buyer case could be considered as further developments of the work.

Keywords: *inventory management, reverse consignment, service parts, repair lead times, maintenance contracts*

Reliability Optimization for Multi-component System in the Design Phase

Qianru Ge, Zumbul Atan, Geert-Jan van Houtum, Ivo Adan

Eindhoven University of Technology, Eindhoven, The Netherlands

We develop an optimization model in which the Life Cycle Costs (LCC) of a multi-component system is mearsured under a performance-based contract with design costs, repair costs and multi-period penalty costs. Since in the design phase for each critical component, the failure rate can be chosen from a certain range. The objective of our research is to determine the optimal failure rate for each critical components in the system, so that the LCC of the system is minimized. Under a performance-based contract, a penalty cost should be paid by the OEM to their customers when the total system downtime exceeds a predetermined level. Furthermore, the penalty costs can be divided into different periods as well as the prdetermined level of the total system downtime which complicates the optimization procedure of our model. The repair costs are determined both by the number of failures and repairs cost per failure, which can be extended to inventory and logistic cost in future research.

Aircraft Repair Process Efficiency Improvements: How to Increase Reliability in a Component Pooling System

Adel A. Ghobbar[1], Isabelle Tozzi[2]

[1] *Air Transport System & Operations Professor, Aviation Management Studies, Prince Sultan University, Saudi Arabia*

[2] *Air Transport and Operations, Faculty of Aerospace Engineering, Delft University of Technology, Delft, The Netherlands*

The maintenance of commercial aircraft is a necessity to ensure safe and efficient operation. In an industry where the demand for safety is high, it is important that the maintenance is performed thoroughly and according to regulations. A downside to this story is that the current maintenance process is too long, which results in a specific maintenance process for each failure. The objective of this research is to increase the performances of the current repair process, when outsourcing the maintenance, and lowering the premature failure rate. The first part of this research is to improve the performances of the repair process. The manufacturer is not performing the maintenance themselves. The maintenance is done by subcontractors all over the world, Original Equipment Manufacturer (OEM) and Maintenance, Repair and Overhaul (MRO) companies. Three different groups were identified; Administration, Logistics, and Repair Shop. With the help of a general linear model, the significance of these three factors was able to be calculated. The significance for Logistics and Repair Shop was high, for Administration it was less significant, but still important.

The second part of this research was to identify the premature failure components and introduce solutions for these components to increase their reliability. For five of these components failure models were used to identify the critical parts within each component. The models used are Failure Modes and Effects Analysis (FMEA), Event Tree Analysis (ETA) and Cause-Consequence Analysis (CCA). Five components were subjected to these models. In the end, all these components had problems with their design.

Keywords: *inventory pooling, outsourcing maintenance, premature failure, repair process, general linear model, failure models*

Impact of Learning on an Imperfect Production Process

Mehmood Khan[1], Matloub Hussain[1], Chaaben Kouki[2], Mohsin Malik[3]

[1] *Abu Dhabi University, Abu Dhabi, United Arab Emirates*

[2] *Essca School of Management, Angers, France*

[3] *University of Melbourne, Melbourne, Australia*

It is generally assumed that every unit of production has an acceptable level of quality, which is not the case in many production environments. Many studies reported that a production process may go out-of-control therefore generating defective items. Preventive maintenance, therefore, is an essential element of the modern manufacturing structure that has been studied through regular interruptions in most of the literature on inventory. Performing preventive maintenance requires a machine (or system) and hence the production cycle to be shut down for a fixed time interval. On the other hand, human learning is another pertinent behavior reported in literature. Although there have been studies that linked learning to production and quality, their results cannot be generalized as they considered a single production cycle. This assumption ignores the transfer of learning that occurs between production (repair) cycles in intermittent environments. This issue would even be of more interest if the production process undergoes a periodic preventive maintenance. This paper addresses this limitation and considers the knowledge transferred from one cycle to another. The amount of this knowledge may deteriorate because of forgetting. A number of costs such as procurement, storage and maintenance would be considered to plan for an optimal production quantity.

The above model should help the researchers and practitioners in supply chains to

(1) Set a stringent policy to curb the defective items reaching the end-customers.

(2) Set optimality criteria for their supply chain framework in the presence of learning.

(3) Highlight the significance of investment in human learning in production environments

The Logistical Consequences of Consolidating Spare Parts with 3D Printing

Nils Knofius, Mattheiu C. van der Heijden, W. Henk. M. Zijm

University of Twente, Enschede, The Netherlands

3D printing offers opportunities to improve spare part supply for capital goods, e.g. by manufacturing parts with a shorter lead time, or by manufacturing consolidated parts with lower failure rates. We focus on consolidation of spare parts which describes the choice to redesign an assembled spare part with fewer, but therefore more complex components. According to the Wohlers report (2014), consolidation is the most important design improvement that 3D printing technology may offer. This manifests itself in various applications in practice. One of the more popular ones is a fuel nozzle used in CFM LEAP engines of General Electric. With 3D printing technology, it was possible to reduce the part count from 18 to 1, and as a consequence, to decrease the weight by 25% and to increase the estimated life duration by a factor of 5 (GE Aviation, 2015).

In our presentation, we discuss which impact consolidation may have on the total costs – in particular due to changing logistics. As such, consolidation may reduce lead times and failure rates but therefore excludes the possibility to store sub-components. Among other aspects, this reduces the flexibility to fulfill a system service level constraint because storage of sub-components to reduce repair lead times is no option anymore. In particular, if characteristics like the demand rate or purchasing costs are varying among the sub-components this affects the total costs negatively however.

Our analysis departs from results in the literature on multi-indenture problems (e.g. van Houtum & Kranenburg 2015) and joint optimization of service decisions (e.g. Basten et al. 2012 or Alfredsson, 1997).

We develop a model which allows a joint optimization of spare part consolidation design and spare part stocks. This model is used to answer the question for which components 3D printing is a good option from a total costs perspective. Also, we use sensitivity analyses to obtain managerial insight about consolidation, i.e., under which conditions consolidation should be considered. In contrast to the general belief in industry, our results show that consolidation is not always a good idea.

Keywords: *spare parts, consolidation, design decisions, stocking policy, lifecycle costs*

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Stock Sharing Method between Regional Depots for Spare Parts of Construction Machinery

Yuhei Niwa[1], Satoshi Sasahara[2], Kentaro Tagichi[1]

[1] *Hitachi, Ltd., Research & Development Group, Yokohama, Japan*

[2] *Hitachi Systems, Ltd., Industrial & Distribution Solution Service Division 1, Tokyo, Japan*

The stock sharing between regional depots is one of the overall optimization method of the stock management in the pyramided supply chain. Normally, the stock sharing provides some good effects that are the reduction of stock quantity, management costs and so on. On the other hand it provides the bad effect that is the increase of the transport cost for the depot-to-depot transport in the same hierarchy. Since these good and bad effects cancel each other out, in order to maximize the effect it is necessary to decide the timing/volume/from-to of the transport. In this study, we aim to improve the consolidated cash flow that we have defined as the effect of stock sharing.

We developed the stock sharing method between regional depots for every replenishment order at depots. In the general operation, if the regional depot wants to be replenished the stock, the central parts depot (CPD) always supplies the stock. In our method other depots, instead of CPD, which have excess stock and can minimize the sum of the 4 cost KPIs which are the purchase cost, the transport cost, the stock management cost and the disposal cost supplies the stock. In our method, since it is possible to supply when the replenishment is needed, it is unlikely to become again excess stock at the replenished depot. And minimizing the sum of these KPIs improve the cash flow. Because, the purchase cost has a direct effect on the stock reduction and other KPIs have a direct effect on the profitability. In addition, our method can evaluate the KPIs with the weight that agreed the business strategy such as the giving priority to the stock reduction, the sales promotion and so on.

We evaluated our method by simulation with actual order data of Hitachi Construction Machinery Co., Ltd.(HCM) which supplies more than 400,000 kinds of spare parts for excavators, dump trucks and so on in their global pyramided supply chain. As a result, the purchase cost was reduce by 3.8%, the transport cost was increased by 60%, the stock management cost was reduced by 3.2% and the disposal cost was reduced by 20% than the general operation. The transport cost was increased, but the profitability was almost equivalent to the general operation. So the consolidated cash flow improved by 10.5%. And the order fill rate is almost equivalent to the general operation.

Keywords: *supply chain management, spare parts, stock sharing, receipt and shipment simulation, construction machinery*

Integrated Planning of Spare Parts and Service Engineers: Full Backlogging

Sajjad Rahimi Ghahroodi[1], A. Al Hanbali[1], I.M.H. Vliegen[1], M. A. Cohen[2]

[1] *Department Industrial Engineering and Business Information Systems, University of Twente, Enschede, The Netherlands*

[2] *Operations, Information and Decisions Department, The Wharton School, University of Pennsylvania, Pennsylvania, USA*

We study a situation where systems installed in a service region are subject to random failures. Each failure (repair call) needs both a service engineer and a spare part to be available before it can be resolved. An inventory is located in the region to supply different types of spare parts. In case of an inventory stock-out, the repair call is backlogged until the requested spare part becomes available. Otherwise, if the requested spare part is in stock, the spare part is reserved and the repair call joins the service engineers queue.

Currently, most companies decouple the above problem into separate problems, one for spare parts planning and one for service engineers. In addition, the integrated planning of these resources has received little attention so far in the literature. However, the simultaneous availability of these resources impacts the service offered to the customer.

We model the system as a queueing network. An exact method and an approximation for the evaluation of a given policy are presented. For the exact method, we model the problem as a quasi-birth-death process and solve it numerically using a standard matrix-geometric method. This method does not scale computationally with the size of the problem. Hence, we develop a fast evaluation method where the average waiting time of repair calls for spare parts is evaluated exactly. For the engineers' queue, we propose an approximation method based on a weighted average of expected waiting time of $M/M/c$ and $GI/M/c$ queues.

We aim to minimize the average total cost under a total average waiting time constraint. The total cost includes spare parts holding cost and hiring cost of service engineers. This results in an integer-programming problem with linear objective function and non-linear constraint. Different optimization methods are developed to jointly determine (sub)optimal spare part stock levels and number of engineers. Then, we compare these methods with separated optimization to investigate the impact of separating the capacity decisions of these two resources.

In summary, using approximate evaluation is necessary for this problem as the exact method fails for problems with more than 3 types of spare parts. Furthermore, by using integrated planning of spare parts and service engineers, we obtain a result with the same service level (total average waiting time) but usually with much lower resources investment in comparison with separated planning.

Keywords: *maintenance logistics, queueing, spare parts inventory, field service, backlogging*

Physical Asset Management Decisions in Infrastructure Companies

Behzad Samii

Technology & Operations Management, Vlerick Business School, Ghent, Belgium

The concept of "asset management" has two individual variations in the academia as well as the business world: physical asset management and financial asset management. In this research, we focus on physical asset management in gas and electricity distribution system operators (DSO). In this traditionally long-life asset environment, the inclusion of delicate electronic sensors (e.g. data transmission-capable oil temperature sensors in field transformers) and data communication modules (e.g. electricity consumption data sent by GPRS modules in smart meters) have impacted the overall cost of preventive and corrective maintenance. The fast pace technology improvements also warrant costly technical upgrades which in turn increase the overall acquisition cost of asset, as well as inventory holding host due to obsolescence.

We model the asset management decision of DSOs as a cost minimization problem that take into account acquisition cost (capex); as well as upgrade, cycle and safety inventory, and maintenance costs (opex) for decisions lead to overall lowest total expenditure (totex). We propose customizable platform design (e.g. one electronic circuit board that can be customized to five different variants of smart meters) to take advantage of flexible design of asset which lead to lower acquisition and inventory obsolescence costs. We use numerical analysis to illustrate the validity of asset decisions suggested by the model.

***Keywords**: physical asset management, inventory management, customizable platforms, perishable inventory, design for asset management*

Effects of Information Sharing by Human Communication on the System that Promotes Supply and Demand Adjustment of Truck and Cargo: Research Study on the Japan Local Network System

Norihito Seki

Faculty of Business Administration, Hokkai-Gakuen University, Asahi-Machi, Toyohira-ku, Sapporo, Japan

This study investigates how information sharing by human communication helps promote the use of information systems that intermediate business; it does so by studying a load-matching system used in the transportation industry. Load-matching system is the system that promotes supply and demand adjustment of truck and cargo, and designed to increase the transportation efficiency of truck company logistics. The use of such a system is expected to greatly improve the transportation efficiency of small to medium-sized carriers, neither of which have a nationwide transportation network or physical distribution bases. Most load-matching systems in Japan are inactive; the Japan Local Network System (JL) is one of Japan's few successful load-matching systems. Unlikely the other load-matching systems, JL holds meetings to share information for load-matching by member frequently. To investigate the effects of human communication on the promotion of transactions, we surveyed the actual use of the JL and verified the effects of personal exchange meetings on the use of the load-matching system.

A questionnaire survey was conducted among 663 member corporations of 51 JL branches (n=101). The survey ran from September 17 to November 24, 2009. The variables used were "access," "entry," and "contraction." The "off-meeting" and "metadata" variables were assumed to affect the access, entry, and contraction variables. Furthermore, we constructed structural equation models with the variable data.

In adopted model, the path coefficients from the access to the entry and from the entry to the contraction showed that an increase in accesses would increase entries and that an increase in entries would increase transaction contracts. The entry has a strong effect on the contraction, indicating that increased information distribution promotes the use of the system. Moreover, Off-meeting increased metadata and metadata done the access, entry, and contraction.

Therefore, we explain its success by investigating the interaction between the information system and human communication. We show that JL encourages its members to communicate and share information in offline settings. The models showed that the information shared by JL members via human communication promoted the use of the information system.

Keywords: *logistics in Japan, load-matching system, Information sharing, human communication, covariance structure analysis*

Using Maintenance Plan in Spare Part Demand Forecasting and Inventory Control

Sha Zhu[1], Willem van Jaarsveld[2], Rommert Dekker[1]

[1] *Erasmus University Rotterdam, Rotterdam, The Netherlands*

[2] *Eindhoven University of Technology, Eindhoven, The Netherlands*

Lumpiness in spare parts demand, which could be extremely heavy, is problematic for inventory managers since it increases the difficulty in demand forecasting largely. For preventive maintenance, the lumpiness in spare part demand is triggered by both the lumpiness in component repairs and the uncertainty of individual probable defective component generating spare part demand. Since maintenance plan provides prior information about defective component arrivals, it captures the lumpiness in component repairs and further explains the lumpiness in spare parts demand to some extent. Maintenance plan might prevent us from keeping redundant inventory in the period when there is no component replacement and allow us to estimate the spare part demand based on component arrivals. Therefore, we can make good use of maintenance plan to improve spare part demand forecasting and inventory management.

We propose an estimation of spare part demand distribution and build a dynamic model to obtain the order policy. We first propose a periodic review, lost sale inventory model which minimizes total inventory holding, shortage penalty and ordering cost under maintenance plan. Next, we explore the relationship between the component repairs and the spare part demand. Assuming the same spare part installed in the same type of component has a constant replacement probability in each time period, we can estimate the probability that a component repair needs a certain spare part. With the information of component arrivals provided by maintenance plan, the number of spare parts demand is then binomial distributed and we can obtain the order policy from the inventory model. We consider two solution concepts, one with and another without maintenance plan, in our inventory model to examine the value of information. Case studies performed on real data show that the total cost is reduced by around 8% using maintenance plan.

Keywords: *preventive maintenance, maintenance plan, spare part, forecasting, inventory control*

Repair Shop Design with Multi-Skilled Servers Using Simulation Integrated Genetic Algorithm

Hasan H. Turan, Andrei Sleptchenko, Shaligram Pokharel, Tarek Y. ElMekkawy

Department of Mechanical and Industrial Engineering, College of Engineering, Qatar University, Doha, Qatar

Downtime of advanced technical equipment is very expensive. One of the ways to reduce it is by immediate replacement of malfunctioned parts by ready-for-use spares. The replaced parts are consequently repaired and placed back to stock as spares. In this study, we focus on the analysis of the repair facility consisting of multi-skilled parallel servers. As repair shops usually handle several types of repairables, assigning different combination of skills to each server can be a better option compared to have every server handling every type of failure. However, designing a repair shops with combination of skills is a challenging problem. To alleviate design issues, we propose a mathematical model that optimizes several performance measures such as total expected cost of holding inventory of spare parts, backorder cost arising from downtime of system due to the lack of spare parts, and cost of having multi-skilled servers that have the ability to repair different types of spares.

Due to the stochastic nature of the problem as well as its computational complexity, Simulation Based Genetic Algorithm (SBGA) is developed as a solution methodology. In each iteration of SBGA a set of feasible solutions are generated for skill assignment problem. Then, these solutions are used as input to the simulation engine. Simulation results for performance measures are recorded at steady state. The algorithm runs back and forth between GA and simulation till a predefined iteration number is reached.

Experimental tests of algorithm are performed with 370 test instances by varying the number of servers and repairable part types. After fine tuning the GA parameters, our methodology provides less than 1% of gap between objective function values between brute-force enumeration and proposed algorithm. This results shows that methodology can be applied on larger problem instances to provide managerial insights for decision makers.

Keywords: *spare parts logistics, multi-skilled server, genetic algorithm, simulation*

Spare Parts Planning for Two-Echelon Networks with Lateral and Emergency Shipments

Erwin van Wingerden, Tarkan Tan, Geert-Jan van Houtum

Eindhoven University of Technology, Eindhoven, The Netherlands

We present a spare parts inventory model for a single-item, two echelon spare parts networks consisting of a central warehouse, an emergency warehouse, and multiple local warehouses. The inventory is managed using a base stock policy. Demand, following a Poisson process, arrives at the local warehouses located nearby the customer(s). If a local warehouse is out of stock we prefer to make use of a lateral transshipment from another local warehouse, for which the sequence at which these local warehouses are checked is determined up front. When none of the local warehouses in this sequence have stock on hand, we request an emergency shipment at the emergency warehouse. When the emergency warehouse is also out of stock, we request an emergency shipment from the central warehouse. If also the central warehouse is out of stock, the spare part is directly supplied from the supplier, which has ample stock. The use of lateral transshipments and emergency shipments is useful when downtime costs are high. We develop a fast approximate evaluation procedure in order to evaluate the key performance measures of the network. These key performance measures are the fraction of demand that is satisfied by the local warehouses, the emergency warehouse, the central warehouse, and the supplier. By decoupling the network into two separate evaluation procedures, we are able to efficiently evaluate the entire network. As these two evaluation procedures do depend on each other's output, we make use of an iterative procedure to combine the two evaluation procedures into a single Algorithm. By comparing the results of the key performance measures with simulation, we measure the accuracy of our approximate evaluation. Finally, we want to look into the benefit of using an emergency warehouse in a spare parts network, and using optimization methods to set the base stock levels within the network.

Keywords: *inventory control, SKUs, system-oriented service constraints, heuristics*

Sustainable Logistics and Supply Chain Management

Integration of Energy Aspects into the Economic lot Scheduling Problem

Fabian G. Beck, Konstantin Biel, **Christoph H. Glock**

Institute of Production and Supply Chain Management, Technische Universität Darmstadt, Darmstadt, Germany

Following the scarcity of resources, rising energy prices and an increasing awareness of the role manufacturing plays in the generation of greenhouse gas emissions, the usage of energy has more and more often made it onto research agendas in the area of production planning over the last decade. This work integrates energy aspects into the well-known economic lot scheduling problem (ELSP) by taking account of the cost arising from the product-dependent energy usage of the production machine during startup and shutdown phases as well as during tool change, idle, and production phases. To determine a cyclic production schedule which minimizes the sum of setup cost, inventory holding cost, and energy usage cost, we use the Common-Cycle-Approach of Hanssmann (1962) and the Basic-Period-Approach of Haessler and Hogue (1976) and adjust them accordingly. Using an extension of the Bomberger data set, we show that considering energy cost in the ELSP may clearly affect the resulting cyclic production schedule and significantly reduce a company's energy cost.

Keywords: *economic lot scheduling problem; energy usage; energy efficiency; production planning; scheduling*

Impact of Coordination on Costs and Emissions in a Two-Echelon EOQ Model

Yann Bouchery[1], Asma Ghaffari[2], Zied Jemai[3], Tarkan Tan[4]

[1] *Ecole de Management de Normandie, Axe Logistique Terre Mer Risque, Le Havre, France*

[2] *Laboratoire Génie Industriel, Ecole Centrale Paris, Chatenay-Malabry, France*

[3] *Université Tunis El Manar, Ecole Nationale d'Ingénieurs de Tunis, Tunis, Tunisia*

[4] *Eindhoven University of Technology, School of Industrial Engineering, Eindhoven, The Netherlands*

Coordination in supply chains consists in aligning the decisions made by several echelons to reach a globally optimal solution called the centralized solution, and to share the benefits among the actors. This concept has been studied widely from a costs optimization perspective but coordination is also proposed by practitioners and academics as a solution to reduce carbon emissions. This presentation focuses on the impact of coordinating inventory decisions by comparing the costs and carbon emissions resulting from the decentralized and the centralized optimal solutions of a two-echelon serial economic order quantity (EOQ) model. Our model accounts for transportation and inventory related costs and emissions and we consider vehicle capacities. We indeed acknowledge that inventory decisions affect the load factor of the vehicle (also referred to as the filling rate), and we investigate if coordination can help increasing the load factors. This is a very important issue as road freight inefficiency is recognized as a major contributor of carbon emissions. We derive new results to solve the problem in the decentralized and in the centralized cases. We provide sufficient conditions ensuring that coordination enables reducing both costs and emissions through an increase in load factors and we show that these conditions are satisfied in many applications. On the other hand, we also identify situations for which coordination leads to an increase in emissions. In such situations, we additionally show how to obtain a solution decreasing both costs and carbon emissions. This proves that pure cost driven collaboration is not always beneficial for the environment. This result is in opposition with the general belief stating that cost and carbon emissions go hand in hand in transportation. We apply multiobjective optimization and we show how this tool can support managers in their assessment. The proposed results would enable companies to focus on the solution that fits the most with their objectives. We show that coordination, if well implemented, may significantly impact the supply chain costs and emissions. We apply our model to an example derived from the retail industry and we derive a series of insights. As the results are general in nature, they may also serve as a guideline for other industrial sectors.

Keywords: *inventory, coordination, carbon emissions, road freight transport, multiobjective optimization*

How to Set Price and Sales Effort in a Supply Chain of Virtual Products Under bi-Criteria and Risk Consideration

Tatyana Chernonog[1], Tal Avinadav[1], Tal Ben-Zvi[2]

[1] *Department of Management, Bar-Ilan University, Ramat-Gan, Israel*

[2] *Wesley J. Howe School of Technology Management, Stevens Institute of Technology, Castle Point on Hudson, Hoboken, USA*

Virtual products such as software, mobile applications, and digital music, have a substantial market size, which has been increasing rapidly in the last two decades. Contrary to tangible products, virtual products are not associated with holding costs, and any demand can be fulfilled with zero lead time and ample capacity. We consider a two-echelon supply chain of virtual products consisting a single manufacturer and single retailer who face an uncertain demand. Demand distribution is affected by selling price and sales-effort investment. The objectives of the manufacturer and the retailer are to optimize one or more profit criteria. By using game theory, we show that the problem can be analytically solved for a common structure of the demand function combined with certain profit criteria. We find that the retailer's bi-criteria preferences may introduce a new source of uncertainty in addition to demand uncertainty. We analyze the case from two perspectives: perfect and imperfect information regarding the retailer's choice mechanism. Under the assumption of perfect information, probabilistic choice theory is used, whereas under imperfect information, normative and behavioral approaches are utilized. Finally, we propose a method to find the efficient sets of decisions for each supply chain member under bi-criteria analysis and provide some numerical results.

Sustainable Supply Chain Collaboration with Outsourcing Pollutant-Reduction Service

Huiping Ding, Hua Huang, Qilan Zhao

School of Economics and Management, Beijing Jiaotong University, Beijing, China

Over the past decades, economic development has caused severe environmental problems that our society faces today, including climate change, ozone decline, nuclear radiation, industrial toxins, widespread air and water pollutions and so on (Cohen and Winn, 2007). Reducing carbon emission and pollutant has become consensus worldwide. However, this complex job needs collaborative efforts of many related aspects, such as governments, enterprises, customers, and the community, etc. (Sommerville, et al. 2010). Pollutant and carbon emission reductions are particularly interconnected with business behavior of supply chain. How supply chain members would collaboratively reduce pollutant and carbon emissions has attracted high attention worldwide. Typically, in the competitive market, the cost disadvantage of internalizing environmental externality presents a major barrier that restrains companies' investment in environmental technology. For instance, coal power plants are discouraged to install pollutant-reduction facilities due to the heavy investment and operating costs. With this consideration, this paper intends to develop a business model in which the operational service of pollutant-reduction including equipment facility as a whole package is outsourced. In the model process, the supplier that provides this service will bear the total cost of equipment facility installation and operational process, in return for its service the supplier earns revenue from a portion of electricity payment collected by the power plant which depends on the sales quantity of electricity during service periods. Our research focuses on the investigation of the mechanism that sustains collaboration between coal power plant and operational service supplier by determining an optimal outsource price. The crucial issue is through negotiating the outsource price to reach the goal of reducing pollutant and carbon emissions and meanwhile satisfy two partners' economic interests.

In this paper, based on the assumption that cooperation in supply chain can collectively reduce pollutant and carbon emissions, by taking the government policies into consideration a business model of outsourcing pollutant-reduction service in the supply chain context is developed with environment constraint, where the objective is to maximize the net present value of the integrated supply chain (including coal power plant and pollution-reduction service provider as partners) together with satisfying the interests of the both partners in terms of profit allotment. A problem solving framework is proposed for optimizing decision making process by determining the optimal outsource price through negotiation between the two partners. Based on the analytical work aforementioned, a numerical analysis is provided to illustrate the model.

The results show that there exists an equilibrium outsource price that satisfies the supply chain partners and meanwhile coal power plant's performance are in compliance with the environment constraint. Our key contribution lies in investigating the mechanism of collaboration with financial feasibility when outsourcing pollutant-reduction service in the supply chain context, where decision making process is based on fulfilling the environmental constraint with taking government policy into consideration. Our research findings have the following implications. First, considering environmental externalities the government's

supervision should have incentives to motivate the cooperation between the supply chain partners. Second, economic scale of output and sales price discount of the generated electricity power are the primary factors that is essential to the service supplier's breakeven affects outsource price negotiation, which reflects the effectiveness of the improvement of supply chain's environmental and business performances.

Keywords: *sustainable supply chain; environment constraint; outsourcing; profit allotment*

Competitive Advantage of Dairy Enterprise Supply Chain: Perspective of Quality and Safety

Yanan Fu, **Huiping Ding,** Kun Xu, Qilan Zhao

School of Economics and Management, Beijing Jiaotong University, Beijing, China

The quality and safety is the most important issue concerned by dairy companies. Throughout entire dairy supply chain, quality and safety problems tend to occur in upstream of the supply chain, i.e. the link of milk source. Therefore, the integration of upstream suppliers in the supply chain plays an important role in the quality management and control of dairy products, which also impacts the competitive advantage of dairy supply chain.

From perspective of quality and safety, this paper focuses on identifying the key factors that affect the quality and safety of dairy products, analyzing business and production behaviors of the suppliers of milk source and manufacturing processing in the dairy supply chain context, addressing the issues related to dairy quality and safety supervision in China context. Emphasizing on quality and safety attributes, the paper also identifies the factors that influence competitive advantage of Chinese dairy companies in the supply chain, including social responsibility, brand image, coordination capability, etc., by using the structural equation model approach. Based on designing questionnaire to collect data and running AMOS software model, our results show that milk source suppliers' safe production behavior significantly affects the quality and safety of fresh milk, the production safety behavior of the organized group of farmers is better than rural households' scatter breeding; on the whole, the quality safety problems in dairy farming link are still very much concerned; supply chain core company's social responsibility consciousness has a great deal of the effect on the coordination of upstream and downstream members, dairy product quality and safety as well as the supply chain competitive advantage.

Enhancing company's soft strength in terms of innovative character and consciousness of product quality and safety differentiates the factors that influence dairy enterprise supply chain competitive advantage, thereby creates a new perspective for the study on supply chain of the dairy enterprises.

Keywords: *dairy enterprise; supply chain, competitive advantage; structural equation; quality and safety*

Pricing Decisions and Coordination in Closed-Loop Supply Chain with Patent Licensing and Remanufacturing Competition

Ju-hong Gao, Meng-meng Li, Jin-hui Teng

School of Management and Economic, Tianjin University, Tianjin, China

With the development of remanufacturing industry, the dispute about intellectual property is getting worse and the conflict of interest between manufacturers and re-manufacturers is becoming more and more serious. Therefore, patent protection is an important factor in remanufacturing closed-loop supply chain (CLSC) decision-making and coordination research. When a firm makes pricing decisions, it must consider the competition in market and the uncertainty of market demand. With the target of maximizing the members' profit, we study the decision-making and coordination problems under random demand with considerations of patent protection and competition in remanufacturing CLSC.

In this paper, the CLSC system which includes a manufacturer, a remanufacturer and a retailer is constructed. And based on Stackelberg game theory, pricing decision-making models is developed and actual example is analyzed in order to investigate the effects of patent licensing fees and remanufacturing competition and the uncertainty of demand on pricing decisions and coordination mechanisms.

Research shows that: patent licensing fees is independent of the model of pricing decision system, but negatively correlated with the recycling cost; manufacturer will pass the increase patent licensing fees on to consumers, and it would reduce consumers' enthusiasm about recycling; with the increase of remanufacturing competition, the sales price and wholesale price of new and remanufactured products will decrease, the expected profits of the CLSC system will increase; with the new and remanufactured products' demand uncertainty increasing, the expected profits of the retailer and the CLSC system will reduce.

From the perspective of CLSC management, manufacturers should make the rational patent licensing fees and maintain the appropriate level of remanufacturing competition in order to achieve efficient operation and profit maximization goal.

Keywords: *closed-loop supply chain; pricing strategy; patent licensing; remanufacturing competition; uncertainty demand*

Evaluation of Sustainability Tradeoffs in Multimodal Freight Transportation Planning

Peter Kelle[1], Mingzhu Jin[2], Helmut Schneider[1], Christoph Claypool[1]

[1] *Information Systems and Decision Sciences, Louisiana State University, Baton Rouge, USA*

[2] *University of Tennessee at Knoxville, Knoxville, USA*

Transportation planners often need to justify transportation related investments to public officials. Besides efficiency measures, the environment protection and sustainability are getting more and more importance. In order to improve freight flow efficiency in a sustainable way, it is necessary to have a systematic tool to study the freight flow over all three major surface modes and their connections and, in turn, to help the public officials identify the best way to improve freight transportation. We built a system-level multimodal simulation model that includes highways, railways, and waterways because all three modes, working together, play significant roles in freight flows. In all existing traffic simulation models, the capacity and volume/speed relationships are only well defined for some infrastructure in a single mode, such as highway links, dams and ports, or rail links. Our simulation model incorporates the connections between different modes. The major outcomes from this research project are:

- A case study that demonstrates how to apply the proposed performance measurement system to evaluate the Louisiana intermodal network for freight management.
- Conduct what-if analysis of the performance of the Louisiana freight network under different scenarios and evaluate the benefits of selected network improvement initiatives.
- Evaluate the tradeoff between environmental goals and other performance measures.

Our ongoing research includes further what-if analysis of the performance of the Louisiana freight network under different scenarios and evaluate the benefits of selected network improvement initiatives. Further, we are working to extend the evaluation and the tradeoff analysis between environmental goals and other performance measures.

Keywords: *sustainability, intermodal transportation, traffic simulation, traffic planning evaluation, performance measurement*

Corporate Governance as a Factor of Building Social Responsibility– Supply Chain Perspective

Danuta Kisperska-Moron

Department of Business Logistics, University of Economics in Katowice, Poland

Purpose: Responsibility of businesses involved in supply chains can increasingly be found high on the CSR-agenda of European companies and governments. Sustainable supply chain management expresses the concept of social responsibility of member organizations for the impacts of their decisions and activities on society and the environment, through transparent and ethical behaviour that contributes to sustainable development, including health and the welfare of society; takes into account the expectations of all supply chain stakeholders; is in compliance with applicable law and consistent with international norms of behaviour; is integrated throughout organizations operating in a supply chain and in its relationships.

It is very unlikely that such complex challenges could be faced by single companies, thus collaboration is necessary among the members of a supply chain. Companies operating in supply chains are quite diversified; they represent different sectors of the economy, and mainly manufacturing, distribution and logistics services. Also various sizes of companies operate in those supply chains.

Building social responsibility in a supply chain requires the presence of certain rules and legal standards, institutional structures and corporate culture which decide about management practices and decision-making processes. Those issues are included in the system of corporate governance (organizational governance) in all companies – members of supply chains. Literature presents different patterns of corporate governance in supply chains but never from the point of view of social responsibility management.

The purpose of this paper is to present results of the research concerning the current practices of governance for corporate social responsibility in supply chain companies and relate those common practices to some successful patterns of organizational solutions in that field.

Research approach: Research instrument used for the data collection was a survey concerning the rules and standards of organizational governance in different types of companies operating in supply chains. Polish managers were the respondents of the survey in 2014. Data analysis provided response to the following research questions:

RQ1: How the type of a company and its role in the supply chain is related to organizational governance for corporate social responsibility?

RQ2: How the size of a company is related to organizational governance for corporate social responsibility?

Three case studies of successful practices of organizational governance for corporate social responsibility served as an example of model solutions in that field.

Findings and originality: On the basis of literature study the set of variables describing practices of corporate governance for social responsibility of companies in supply chains has been identified. The results of data analysis showed that there are noticeable differences of

strategic managerial attitudes towards governance solutions in the field of social responsibility depending on the type and size of a company. Large companies and manufacturers seem to adopt more often adequate strategic solutions in that field. However, when specific social responsibility rules are concerned, different attitudes of companies appear. Some recommendations for model solutions of organizational governance have also been provided. According to the knowledge of the author of the paper such aspects of governance in supply chain companies for building social responsibility have not been widely discussed in literature yet.

Research impact: Research highlights the problems of profiles of corporate governance for building social responsibility in different types of companies operating in supply chains. The gap between average company practices and the most successful patterns has been demonstrated. The paper presents the results of studies which can serve as an outgoing point for further more detailed research.

Practical impact: Research results might be of importance for decision makers and managers in companies operating in socially responsible supply chains. They can use the results as a guideline for their managerial practices.

Keywords: *supply chain governance, corporate social responsibility, socially responsible supply chains*

Fuzzy Assessed Locations for Urban Cogeneration Plant as a Node in the City's Circular Economy, Based on MRP Approach

Danijel Kovačić[1], Janez Usenik[2], Marija Bogataj[1]

[1] *MEDIFAS, Šempeter pri Gorici, Slovenia*

[2] *University of Maribor, Faculty of Energy Technology, Krško, Slovenia*

Modern urban planning approaches are turning towards waste free society and cleaner environment. In industrialized society growth of cities and increased consumption of goods resulted in expanded landfill areas. Many of those areas are recognized as over dimensioned nowadays. The fact that closed loop supply chains are gaining popularity is, among others, a consequence of higher environmental restrictions, which reflect through strict legislation, and direct financial costs (penalties) of all kinds of pollution. The future of the smart city concept lays in general optimization of the whole circular economies of the cities, where reduction of waste in approach to production and reuse play one of the crucial roles. One of the effective ways to reduce "excess inventories" of waste on cities' landfills is to build cogeneration plants. Waste is transformed back to heat/energy which is used to supply the city.

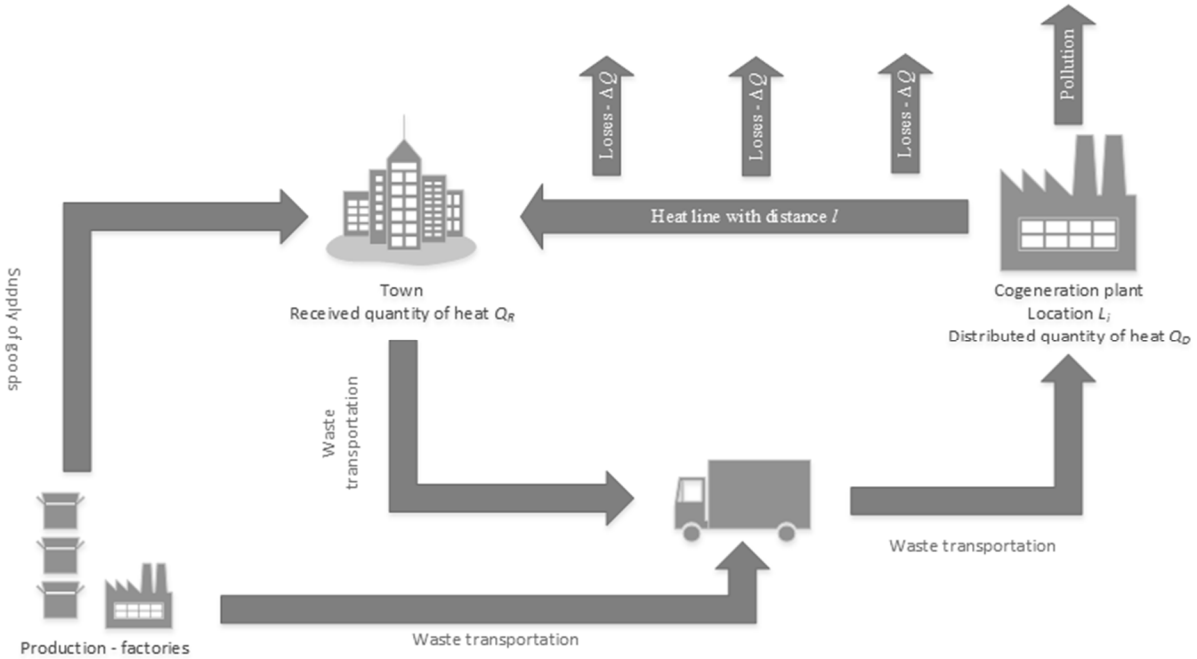

Figure 1: Schematic presentation of city's circular economy.

Such a model is schematically presented at Figure 1. City consumes produced goods, and waste is transported to cogeneration plant at location L_i where it is transformed to heat using the burning processes. Distributed quantity of heat Q_D differs from the actually usable heat

received in the city (Q_R) due to losses throughout the distribution line ($\Delta Q = Q_D - Q_R$). Loses, maintenance costs and transportation costs are all expected to rise with the distance l between cogeneration plant and the city. On the other hand, increasing the distance l of cogeneration plant from the city would make location L_i more competitive due to lower price of the land and lower direct impact of the pollution to urban society of the city.

Where is the equilibrium? Which location from the set of potential locations is optimal? MRP Theory has proven through multiple previous works that it can transparently model complex closed systems of production, distribution, consumption and reverse logistics. A model of input-output matrices is used to mathematically describe material flows in such a system, and Laplace transforms are used for exact introduction of lead times. This allows to financially evaluate the model using Net Present Value (NPV) principles. Here negative contributions such as pollution have negative price, and consequently negative contributions to overall NPV. We will show how to choose optimal location of cogeneration plant with NPV maximization and apprise how successful can be a fuzzy approach in such reasoning.

Keywords: *fuzzy assessed locations, urban studies, circular economy, location theory, MRP theory*

Service Capacity Procurement of Logistics Service Supply Chains with Demand Updating and Loss-Aversion Behavior

Weihua Liu, Donglei Zhu

College of Management and Economics, Tianjin University, Tianjin, China

This paper studies the service capacity procurement of logistics service supply chain in which supply chain members have loss-averse preferences and market demand is updated. An LSSC with one loss-averse logistics service integrator (LSI) and one loss-averse functional logistics service provider (FLSP) is investigated. A basic two-stage model is built with the aims of maximizing the utility of the LSI and FLSP at a certain service level. We further consider other three models of special scenarios. The impact of loss aversion on the decisions of the LSI and FLSP are discussed by comparing the four models. Our analysis generates many conclusions. First, under certain conditions, the total volume of service capacity purchased by the LSI will decrease when demand is updated, and the LSI's total service capacity will decrease with the service level, regardless of whether or not the supply chain members have loss-averse preferences. Second, the service level can affect the LSI's procurement strategy and the FLSP's pricing strategy. This effect is related to the loss-averse preferences of the FLSP, but not to those of the LSI. Third, the loss aversion of the LSI and FLSP can affect the decisions of supply chain members only if certain conditions are satisfied.

Keywords: *supply chain management; demand updating; loss-aversion; procurement*

A Multi-Objective Robust Stochastic Model for a Transshipment-Enabled Inventory Routing Problem in a Green Supply Chain

Seyed Mohammad Javad Mirzapour Al-E-Hashem[1], Yacine Rekik[2]

[1] *Department of Industrial Engineering, Amirkabir University of Technology, Tehran, Iran*

[2] *EMLYON Business School, DISP Lab, Ecully, France*

Recently, 'greenness' has become a very much needed condition in the transportation industry. In this study we develop a 'green', transshipment-enabled model for the Inventory Routing Problem (IRP), in a many-to-one distribution network where demand for each product is realistically assumed to be uncertain. The proposed framework is a multi-objective robust stochastic programming model. The first objective function aims to minimize the weighted sum of the expected value and variance of the supply chain costs (including inevitable shortages) plus the infeasibility penalty function. The second objective aims to minimize the total quantity of the greenhouse gas (GHG) emission produced by the vehicles and scraped products. The green considerations, model and solution robustness, the option of transshipment and the assumption of demand uncertainty constitute collectively a significant departure from the current state of knowledge in this area. Two evolutionary algorithms are then proposed to solve the model; MOPSO, and NSGA II. A numerical study allows insights to be gained into the performance of the model, efficiency of the algorithms and other important managerial concerns. The results show that how companies can make a reasonable tradeoff between the economic and ecological concerns.

Keywords: *inventory routing problem; stochastic programming; transshipment; green supply chain; uncertain demand*

The Logistics Integration of Small-scale Farmers in Modern Supply Chains: The Role of Social Enterprise and Sustainable Design in Thailand

Suthep Nimsai[1], Pattana Boonchoo[2]

[1] *Business Economics and Logistics Research Excellence Centre, School of Management, Mae Fah Luang University, Chiang Rai, Thailand*

[2] *Thammasat Business School, Thammasat University, Bangkok, Thailand*

Agri-food systems have faced dramatic changes in both developed and developing economies. The systems that were based on traditional markets are immensely channeled through modern supply chains. While this situation offers opportunities for small-scale farmers, the high standards set by modern supply chains in terms of quantity, quality, delivery, timing, packing, and safety prevent small-scale farmers from exploiting these opportunities, because of the significant changes required in their production, marketing and logistics systems. In recent years, social enterprise emerged in both developed and developing economies in integrating small-scale farmers with modern supply chains. The objective of this study is to assess the impacts of the logistics integration of small-scale farmers in modern supply chains and the role of social enterprise and sustainable design in Thailand. The study is based on a case study of social enterprise. An applied value-chain and New Institutional Economics (based on transaction costs) framework is used to analyse how small-scale farmers are coping with the transformation and sustainable design in the food sector in Thailand.

The findings indicated that there were many reasons for participant farmers in participating the social enterprise and the reasons were varied. Firstly, transaction cost such as access to information and inventory management were of vital important. Participation in the social enterprise scheme helped reduce the transaction costs and also increase the ability to plan and allocate resources efficiently. Social enterprise helps to reduce logistics and inventory costs faced by small-scale farmers. Logistics and inventory costs, in terms of food waste in case of lover integration then were identified in the study whilst the lower integration includes a shorter process of supply chain. Secondly, market demand such as level and variability of market demand drives benefit for participating farmers, enabling them to increase productivity and selling above that of non-participating farmers. Finally, market competition such as level of market price and place of selling was in highly concern of participant farmers for participating in the social enterprise scheme.

Keywords: *logistics integration, sustainable design, modern trade chains, social enterprise, inventory management*

Acknowledgement:

This paper is one of research results of 'Organic Food Value Chain Restructuring and Marketing Strategies for Supermarkets and Exporting in Thailand' a research program granted by Thailand Research Fund. The author wish to thank to Professor Dr. Demeter Krisztina, Corvinus University of Budapest for useful comments and suggestions. Moreover, the author wishes to express his gratitude to Mae Fah Luang University and many individuals for theirs contributions to this research project.

Sustainable Sourcing of Strategic Raw Materials by Integrating Recycled Materials

Patricia Rogetzer, Lena Silbermayr, Werner Jammernegg

WU Vienna University of Economics and Business, Department of Information Systems and Operations, Vienna, Austria

Objectives of study*:* Recycling makes it possible to integrate raw materials out of steadily increasing waste streams back into production processes and at the same time contributes to a reduced dependency on imports. Considering such an alternative supply option can increase the economic, environmental and social sustainability of supply chains. Moreover, it enables resources being used more efficiently. Currently, a lot of research is done in the area of establishing technical possibilities for efficient recycling of strategically important raw materials for the electronics industry. Though, quantities resulting from recycling processes are still uncertain and therefore, demand cannot be met by this secondary source alone and the primary mining source is still needed. Nevertheless, having an alternative supply source in place enables manufacturers to reduce supply risks and increase sustainability.

Materials and Methods*:* In this paper, we investigate a company's sourcing decision where strategic materials can be procured from a primary raw materials supplier and from a secondary recycling source, hence taking into account new and recycled materials simultaneously. Considering uncertain prices for recycled materials, uncertain recycling quantities and uncertain demand as well as their potential dependencies we develop a single period inventory model.

Results*:* We derive the order quantities for recycled and primary materials, the related costs and evaluate the effectiveness of the sourcing strategy. We provide managerial insights in the economic and environmental benefits of multiple sourcing with recycling and compare this strategy to the option without recycling. We conduct a detailed numerical sensitivity analysis on the key input parameters.

Conclusions*:* The aim of this paper is to show to what extent recycling contributes to the company's value by means of improving the supply security through a secondary sourcing option and enhancing the company's image by being more sustainable.

Keywords*: newsvendor, multiple sourcing, uncertain recycling quantities, uncertain prices, correlations*

Time Slot Management Systems for Warehouse Loading Docks – A Simulation-based Analysis of the Behavior of Warehouse Operators

Ralf Elbert, **Dominik Thiel**

Technische Universität Darmstadt, Darmstadt, Germany

The cost structure of road freight carriers and forwarders is increasingly influenced by the extensive use of slot management systems by warehouse operators. The resulting time window constraints with potential consequences in case of late arrivals add complexity to the planning and execution of road transport services.

Especially the behavior of warehouse operators and the enforcement of time slots have impact on the complexity and thus cost of road transport services. Usually this behavior, in case of a missed time slot or in general a late arrival, is fixed towards a group of carriers and forwarders. So (stable) behavioral patterns can be identified and described. Through literature review and interviews with German shippers, carriers and forwarders four general patterns of behavior evolved as follows:

(1) No consequences --> direct dispatch

(2) Penalty --> paying a fixed or variable financial penalty

(3) Queuing --> waiting for a free (unbooked) time slot

(4) New booking --> booking of a new time slot

In order to quantify the financial impact of time slot management and the resulting time window constraints for road freight transport services, the consequences of these identified behavior patterns are investigated by a simulation study.

With the help of a simulation model the various behavior patterns of warehouse operators are evaluated with regard to the resulting cost of road freight transport services. To provide profound and realistic results, the driving, operation and waiting times are based on empirical data from German road freight forwarders.

The results show deviating financial (quantitative) effects of time window constraints for each of the four described behavior patterns of warehouse operators on the cost structure of road freight carriers and forwarders. This deviation need to be considered for planning, thus new challenges are arising from the ongoing enforcement of slot management systems. Therefore, the consideration of the behavior of all actors can improve the reached results of the planning and execution of road transport services. Furthermore, the research results show that time window constraints as well as the behavior of warehouse operators have a relevant influence on the overall costs of road freight transport.

Keywords: *warehouse loading dock, time slot management system, time window, warehouse operator's behavior*

Effects of Inventory Related Costs on Supplier Evaluation

Imre Dobos, **Gyöngyi Vörösmarty**

Corvinus University of Budapest, Institute of Business Economics, Budapest, Hungary

The paper will investigate a green supplier selection problem. We generalize our results of green supplier selection problem (Dobos-Vörösmarty, 2014). In our former paper we have developed a DEA-type supplier selection method where the output variables of a DEA model were the environmental factors and inputs of the analysis were the management variables.

The new model examines the effect of inventory related costs, such as EOQ costs of inventory holding or ordering costs, on the selected supplier. Another question is, how the lot size of an inventory model influence the supplier evaluation and selection process, not only the magnitude of the inventory level, but also the cumulated inventory related costs.

Keywords: *supplier selection, sustainability, inventory control, EOQ, DEA*

Acknowledgement

The authors are supported by OTKA K 105888.

Reference:

Dobos Imre, Vörösmarty, Gyöngyi (2014): Green supplier selection and evaluation using DEA-type composite indicators, International Journal of Production Economics 157, pp. 273-278.

Positioning the State of Purchasing in Small and Medium Sized Enterprises (SMEs)

Seung-Kuk Paik, **Andrew Yao**

Systems and Operations Management Department, David Nazarian College of Business and Economics, California State University, Northridge, USA

This study examines the distinct purchasing activity of small and medium sized enterprises (SMEs) under the two dimensions of the purchasing portfolio matrix. Resulting analysis presents the current state of SMEs' purchases, measures the degree of SMEs' purchasing development, and compares the degree of SMEs' purchasing development among each of the four stages of SMEs' purchases. This study found that the majority of SMEs' purchases require materials management emphasizing effective cost and materials flow management. Results also indicated that SMEs showed some similarities and differences in their purchasing development.

Keywords: *purchasing, portfolio models, small business, supply chain, survey*

An Empirical Study of Sustainability in the Oil and Gas Industry

Yahaya Y. Yusuf[1], Jan Hewitt[1], Tijjani Abubakar[2], Louise Mc Ardle[1], Wendy Auchterlounie[1]

[1] *School of Management, University of Central Lancashire, Preston, United Kingdom*

[2] *Department of Management and Information Technology, Abubakar Tafawa Balewa University, Bauchi, Nigeria*

Objectives of study: The diffusion of sustainability practices is fraught with a number of challenges. Innovation and process change needed introduce significant cost elements. There is the challenge of justifying to boards and shareholders of a company the need for significant expenditures to protect the environment, in addition to internal inertia and resistance to change coupled with lack of understanding of the objectives and competitive advantages of embracing sustainability. Also, some of these challenges are not well understood. Therefore, in a key industrial sector such as the oil and gas, where business activities do significantly impact the environment, it is important to understand the nature of the bearings sustainability has on business performance and competitiveness. It is equally important to understand the drivers and barriers to sustainability in the sector. This paper, therefore, sought answers to what is/are (i) the level of sustainability practices in the UK oil and gas industry, (ii) the enablers and inhibitors of sustainability in the UK oil and gas industry, and (iii) the impact of sustainability on operational performance and competitiveness in the UK oil and gas industry.

Methods: A survey by questionnaire research methodology was adopted. A total of five hundred and fifty questionnaires (550) were sent out and 162 responded, giving a response rate of 29.5%, but only 112 were fully completed and subsequently used for analysis with SPSS 21 for Windows.

Results: The results indicate that there is a sustained level of sustainability implementation in the oil and gas industry. The drivers of sustainability include energy conservation, increase market share, environmental advocacy pressures and resource depletion. However, legal and regulatory pressure was not seen as a driver. The inhibitors of sustainability practices are inappropriate infrastructural facilities, unskilled employees, insufficient information and high cost of adoption.

Conclusions: Sustainability practices in the industry lead to improved environmental performance and economic performance, with positive influence on operational performance. Our research provides a strong basis for market-driven sustainability by establishing empirical link between sustainability practices and organisational competitiveness and in effect provides a new insight into the foundation for market justification for adoption of sustainability practices in the oil and gas industry.

Keywords: *sustainability, enablers, inhibitors, oil and gas, and competitiveness*

Inventory Policies for Energy Storage Systems Optimalization

Beatrice Marchi[1], **Simone Zanoni[1],** Lucio E. Zavanella[1], Konstantin Biel[2], Christoph H. Glock[2]

[1] *Department of Mechanical and Industrial Engineering, Università degli Studi di Brescia, Brescia, Italy*

[2] *Institute of Production and Supply Chain Management, Technische Universität Darmstadt, Darmstadt, Germany*

The proper design of energy storage systems is getting more and more important in practice. Energy storage system are a promising way to further expand the renewable energy sources' (RES) power capacity and to improve the profitability of these systems. In fact, supporting an RES with an electrical energy storage system (EESS) helps to balance energy supply and demand enabling non-simultaneous energy generation and consumption. The present paper aims to adopt traditional inventory management policies, generally applied to regular commodities, for optimally sizing and managing an EESS for a user of a renewable energy source (such as a photovoltaic system or a wind turbine). Typical cost components for inventory management and supply chain characteristics are, thus, translated into the EESS model. In addition, specific characteristics and the uncertainty inherent in the integrated EESS and RES system are taken into account in the inventory model proposed.

Keywords: *energy storage system, inventory policy, operation management, uncertainty*

Procurement and Coordination under Imperfect Quality and Uncertain Demand in Reverse Mobile Phone Supply Chain

Amy Zeng[1], Jing Hou[2]

[1] *Foisie School of Business, Worcester Polytechnic Institute, Worcester, USA*

[2] *Hohai University, Nanjing, China*

Objectives: As large volumes of new smartphones and tablets hit stores, people upgrade their used devices very quickly, most of which can still find a good length of remaining life. Therefore, the second-hand mobile phone business has a great deal of potential from both economic and sustainable perspectives. This research focuses on the used mobile phones that can be sold at a lower price to the markets where customers are more price-sensitive. Specifically, this research aims to examine the procurement and coordination issues in reverse phone supply chains with imperfect quality and uncertain demand.

Methods*:* The research employs a combination of literature review, case study, optimization modeling and numerical experiments to understand the decisions of the two major supply chain players, namely the take-back firm (a "buyer") and the OEM (a "supplier"), with respect to their procurement decisions under imperfect quality and uncertain consumer demand. The interplay between sales quantity discount and quality improvement investment is examined when the two parties want to collaborate. Newsvendor-based models are formulated to study three decision-making situations: without quantity discount, with quantity discount, and with coordination.

Results*:* Under a quantity discount scheme, the supplier provides discount to induce larger orders, where the buyer accepts all the products, including Grades A, B and C used phones (Grades A&B can be sold immediately). The buyer also considers motivating the supplier to invest in quality improvement by employing a two-stage payment scheme that includes an initial payment for a proportion of the total purchase quantity and a higher price for the rest of the Grades A&B phones, while Grade C product is returned to the supplier. We have found that if the initial imperfect quality percentage is low, quantity discount is selected; otherwise, coordinated quality improvement with a two-tier payment is preferred, and the benefit of quality improvement increases with either the initial imperfect quality percentage or the initial purchase cost, but decreases with the demand uncertainty.

Conclusions: The extremely short life cycles and rapid advent of new technologies are placing used cell phones at the forefront of reverse supply chain implementations. This research represents one of the first efforts to investigate the reverse mobile phone supply chain procurement and collaboration under both imperfect quality and uncertain demand.

Keywords: *reverse supply chain, procurement, imperfect quality, uncertain demand, coordination*

Best Student Paper Award Finalist

Assortment and Pricing in Production/Inventory Systems

Hamed Jalali[1], Raïsa Carmen[1], Inneke Van Nieuwenhuyse[1], Robert Boute[1,2]

[1] *Research Center for Operations Management, Department of Decision Sciences and Information Management, KU Leuven, Leuven, Belgium*

[2] *Technology and Operations Management, Vlerick Business School, Leuven, Belgium*

For long, researchers and practitioners have been aware of the importance of aligning marketing decisions with the capabilities of the production system. Most of the existing models, however, make simplistic assumptions about the production capacity and thus do not capture the production lead time in a realistic manner. In this paper, we consider the impact of load-dependent lead times on the optimal assortment and pricing decisions of a make-to-stock manufacturer, who wishes to offer an assortment of vertically differentiated products (i.e., having different quality levels) to the market using a given (flexible) production capacity. Depending on the price and quality levels of the products offered, customers decide to either buy a given product, or not to buy at all. Inventories are reviewed periodically, and the goal of the manufacturer is to set the price, quality and inventory levels of the products to maximize long-run expected profit. For the sake of clarity, we limit the assortment to two products and fix the quality of one of the products.

We first characterize the optimal decisions assuming no coordination between marketing and production departments: the marketing department is uninformed about the impact of its price and quality decisions on the production lead time so it assumes a fixed exogenous lead time (e.g., based on past experience; *uncoordinated system*). For normally distributed demands, the optimal decisions then have a simple structure. Next, we study the results of the *coordinated system* where the marketing department has perfect information about the impact of its decisions on the production lead time (i.e., lead time is endogenous and load-dependent). We assume that a single processor sequentially processes items one at a time on a FCFS basis and that the production time increases with the product quality level. To analyze the optimal decisions in this system, we build a queuing model and solve it using matrix analytic techniques.

We show that lack of production-marketing coordination causes suboptimal assortment and pricing decisions, resulting in significantly lower profits for the firm. More specifically,

the firm opts for excessively high quality levels and sets the price of the higher quality product too low. This will cause the utilization of the production system to soar and leads to high congestion levels and long production lead times.

Keywords: *assortment, pricing, production/inventory system, vertical differentiation, production/marketing coordination*

Commodity Spot Market Procurement under Hidden Markov Modulated Price Regimes

Christian Mandl, Stefan Minner

Logistics & SCM, Technical University Munich, School of Management, Munich, Germany

An increasing number of companies buy their raw materials like metals or agricultural commodities at spot markets that are characterized by a high and still further growing price volatility. In addition, due to different states of the world - e.g., good and bad economic conditions or periods of desirable and periods of undesirable weather conditions - dynamics in spot prices are not stationary.

Financial research shows that these states (price regimes) in general are not directly observable, the current price process or its parameters are not known with certainty. A common tool to deal with unobservable states of the world are hidden Markov regime switching models.

We propose an approach where price observations at the spot market are considered in order to update probabilistic price regime information (that is, e.g., derived from historical data) in a Bayesian fashion. We then use a state-of-the-art price model from finance as input for a discrete time, periodic review inventory control model under uncertain demand and prices.

We show that under this setting the well-established price-dependent base-stock policy is not sufficient for inventory control and demonstrate how to interpret the optimal state-dependent inventory policy if the states are not observable. To this end, we proof that a price(s)- and belief-dependent policy is optimal if the price follows a doubly embedded stochastic price process that is described by a hidden Markov model. We differentiate between Non-Markovian price processes and (first-order) Markovian price processes inside the regimes and point out that this distinction makes a difference when it comes to the optimal base-stock function.

We also investigate different monotonicity conditions and demonstrate under which settings it is beneficial to order more at higher prices.

We illustrate that optimal inventory decisions are affected when we explicitly model prices as a Markov regime switching process and that ignoring regime shifts, even if they are unobservable, leads to non-optimal decisions and significant cost drawbacks. We show in numerical illustrations under which settings of price process, demand and cost structure it is particular beneficial to consider price regimes and when a regime framework is negligible from an inventory control perspective.

Finally, we compare several computationally appealing suboptimal control policies to solve the partially observable decision problem with exponentially increasing state space more efficiently.

Keywords: *regime switching, stochastic price and demand, belief-dependent base-stock policy, Bayesian learning, dynamic programming*

The Influence of Quality Inspections on the Optimal Safety Stock Level

Danja Sonntag, Gudrun P. Kiesmüller

Faculty of Economics and Management, Otto von Guericke University Magdeburg, Germany

Due to yields of less than 50 percent during the production of curved glass for displays of the new cell phone series, Samsung has to deal with higher than expected production costs of several million dollars. In case of random yield, production costs as well as inventory holding costs can be reduced by introducing quality inspections which eliminate defective items before further production. To achieve maximal cost savings, it's important to determine the optimal number and location of these inspections across the production process to obtain real time yield information, which is not simple due to several influencing parameters.

We consider an in-house multi-stage serial production system without interim storage between the production stages but with a warehouse for the final product. Each production stage is related to stochastic proportional yield and a production time. At the beginning of each period the warehouse can place an order at the production system. Since the optimal ordering policy in case of random yield and positive production time is very complex, a linear inflation rule is used to determine the production quantity. The demand which has to be fulfilled by the warehouse is stochastic and independent and identically distributed across the periods. Demand which cannot be satisfied is backlogged. At the end of each period holding and backorder costs are charged.

Using an approximate steady state analysis we obtain an analytical expression for a near optimal pseudo order-up-to level under real time yield information. We show how the location of inspections within a production process influences the optimal safety stock level, required to buffer against uncertainties due to demand and yield randomness, as well as overall costs. We further illustrate that in general, for symmetric yields across the system it is best to locate control points equally spaced across the production periods to minimize overall costs. We achieve a maximum safety stock reduction of more than thirty percent in our examples which can be even larger depending on the parameter setting. For a company like Intel, reporting inventories for finished goods of nearly 1.5 billion dollars in the 2014 annual report, this is a possibility for significant savings.

Keywords: *stochastic inventory model, random yield, quality inspections, linear inflation rule, steady state analysis*

In-Absentia

Sales and Operations Planning in Case of High Product Mix and High Market Uncertainty: A Case Study

Marco Busi, Francesca Plebani

Carisma RCT, Aberdeen, United Kingdom

Objectives of the study: The project behind this paper aims to support Sales and Operations Planning (S&OP) in situations where high product mix and market uncertainty make it difficult to adopt current demand management, forecasting and production planning theories and off-the-shelf tools.

Materials and Methods: Much has been written about demand management and S&OP and the plethora of formulas that can be used to analyse and forecast demand and plan production. Nevertheless, we found important gaps in the state of the art regarding applications in high product mix and market uncertainty contexts.

Using a longitudinal case study, we collected data on demand, forecast, MRP, products, service level, customer satisfaction, supply chain management, etc. We then used available theories to analyse forecast accuracy, demand profile, product mix, stock and production performance, etc. Finally, as is often the case with action research studies, we used a cycle of deduction and induction to propose a product grouping logic; identify a structured approach to analyse the company's performance in managing products in each group; and rank improvement opportunities.

The longitudinal case study was based at a multinational manufacturing company working with 15,000 stock keeping units and selling to 45 countries in the world, each with specific product preferences. As the company manufactures heating brassware products for the residential sector, its market is tightly linked to that of residential construction, in turmoil since the 2008 financial crisis. Demand, therefore, is highly uncertain and difficult to forecast.

Results: We engineered a simple S&OP process that allows for modelling and managing a complex product and market reality. Its implementation is enabled by:

A multi-criteria logic to group products based on service level, inventory management performance and forecast accuracy. This allows for identifying product groups that may require a different operations or planning strategy.

A series of guidelines to interpret risk levels and improvement opportunities. This allows for ranking the various groups in terms of their risks/reward ratio.

A simulation tool that enables users to simulate the impact that different operational choices may have on stock levels, service levels, inventory costs, etc.

Conclusions: The level of complexity and dynamism of todays industry and markets renders available theories for demand management and operations planning inadequate. This study contributes to knowledge as it fills a gap in the state of the art concerning management of S&OP in cases of high product mix and market uncertainty. It contributes to practice as it gives practitioners an easy to use analytical logic and tools to reduce the complexity of the analysis required to appropriately plan operations.

Keywords: *inventory management, operations strategy, S&OP, demand management, production planning*

A Two-Stage Supply Contract with Risky Supplier and Forecast Updating

Ali Cheaitou[1], Rima Cheaytou[2]

[1] *SEAM Research Group and Industrial Engineering and Engineering Management Department, College of Engineering, University of Sharjah, Sharjah, United Arab Emirates,*

[2] *Aix-Marseille Université, Institut de Mathématiques de Marseille (I2M)- CNRS UMR7373, Centrale Marseille, France*

We develop a single product two-stage supply contract where a retailer buys a number of supply options from a main supplier at the beginning of the decision stage. The retailer faces a random demand concentrated in the second stage (period) and is modeled using a joint probability distribution with an exogenous information. In addition, the retailer has a second supply option from a risky supplier whose availability is modeled using a binomial distribution. At the beginning of the second decision stage, the stochastic exogenous information is revealed and the demand forecast is updated conditionally knowing the value of the exogenous information. Moreover, at the beginning of the second decision stage, the information about the availability or unavailability of the risky supplier becomes known with certainty. Therefore, the supply options bought from the main supplier can be transformed at the beginning of the second decision stage fully or partially into orders and delivered immediately. Moreover, if the risky supplier is available, then a number of additional orders may be ordered and delivered immediately from this supplier. The end customer demands occur during the second stage and every satisfied demand is charged a certain price by the retailer. At the end of the selling season, any remaining units are salvaged by the retailer at a salvage value.

We model this problem using a dynamic programming approach and we exhibit some characteristics of the structure of the optimal policy for the retailer for both available supply options. We provide the structure of the second decision stage optimal policy and some analytical insights concerning the first stage optimal policy. Furthermore, through a numerical study, we analyze the effect of some of the model parameters on the optimal policy especially the information quality, the probability of the availability of the risky supplier, the difference in the costs of the two supply options and the other economic parameters.

Keywords: *inventory control, dual supply, risky supplier, forecast updating, short life-cycle products*

Inventory Classification Using Hybrid Approaches: A Comparative Study

Hedi Cherif[1], Talel Ladhari[2,3]

[1] *Institut Supérieur de Gestion de Tunis, Université de Tunis, Tunis, Tunisia*

[2] *College of Business, Umm Al-Qura University, Umm Al-Qura, Saudi Arabia*

[3] *Ecole Supérieure des Sciences Economiques et Commerciales de Tunis, Université de Tunis, Tunis, Tunisia*

The ABC classification is one of the most frequently analysis used in production and inventory management domains, in order to classify a set of elements in three predefined classes A, B and C, where each class follows a specific management and control policies, in order to generate companies financial well-being. This paper introduces new approaches for the multicriteria inventory classification based on the hybridization of the Differential Evolution algorithm (DE) with three multicriteria decision making methods namely Topsis, Electre III and Vikor. The evolutionary algorithm (DE) attends to optimize the input (criteria weights) of MCDM methods. MCDM methods generate a score for each item using an aggregation function that combines the item evaluations on the different criteria and the criteria weights. Once the items ranked using the score of each item, the first 20% items with higher score are classified in class A, The next 30% items are classified in class B and the remaining items (50% of total items) are classified in class C. An inventory cost function is used thereafter to evaluate each established classification. This inventory cost function is based on different inventory costs (ordering cost, holding cost, shortage cost) and service level measurement (cycle service level, fill rate) and also represents the objective function of our model, which consist of minimizing the inventory cost. The highlight of the three proposed hybridization approaches (DE-Topsis, DE-Electre III and DE-Vikor) is the exploitation of the robustness and usefulness of both DE and MCDM techniques. To test the performance of the proposed three hybrid approaches with respect to some others ABC inventory classification models, a benchmark data set of 47 items from a Hospital Respiratory Therapy Unit is used. Based on results generated, a comparative study was conducted to compare our three hybrid models with other ABC classification models of the literature. The 3 models provided encouraging results, outperforming the most common classification algorithms.

Keywords: *ABC inventory classification, Differential Evolution, Topsis, Electre III, Vikor*

Effects of Inventory costs on the Capacitated Lot-Sizing with Setup Carryover and Setup Splitting

Srimathy Mohan[1], Cheng-Lung Chen[2], Muhong Zhang[1]

[1] *Arizona State University, Tempe, Arizona, USA*

[2] *Ohio State University, Ohio, Columbus, USA*

One of the recent research trends in the big bucket capacitated lot sizing problem (CLSP) is the inclusion of carrying over the setup state across periods and allowing the duration of a setup to cross period boundaries. Considering setup carryover and splitting in the formulation generally generates a better production schedule in terms of lower costs and at times, removes infeasibility from models that do not consider setup carryover and splitting. However, the resulting model and the solution procedures tend to be more complex and computationally more expensive. In this research, we present a model for the CLSP with setup carryover and setup splitting (CLSP-SCSS) and develop an efficient fix-and-optimize heuristic. We utilize this heuristic to investigate the effect of inventory costs on the inclusion of setup splitting in the resulting production schedules.

We formulate the CLSP-SCSS as a mixed integer model using a simple plant location reformulation and add three types of valid inequalities to tighten the formulation. We develop a generic fix-and-optimize heuristic to solve the model. The heuristic fixes the value for a small set of the binary setup state variables and the model with the remaining binary variables and continuous variables is solved to optimality using a branch-and-bound procedure. The heuristic uses iterative product and period decomposition procedures to develop a good solution to the initial model. We have also extended the model and heuristic to accommodate demand backlogging. The proposed model and heuristic was coded using AMPL and solved using IBM ILOG CPLEX 12.0.6.1.

We tested our heuristic on the data sets from Trigeiro et al. (1989) and Belo-Filho et al (2013). The experiments vary the capacity of periods, demand, setup cost, setup time as well as inventory costs. Our experimental results indicate that the proposed heuristic is very efficient and produces solutions within 6% and 8% of optimality for data without and with demand backlogging respectively. The experimental results also show that setup splitting is essential for finding a feasible solution when setup times are long, problem size increases, as well as when inventory costs increase. When inventory costs are high, it becomes advantageous to produce closer to the actual demand and this might require splitting setups across periods, when capacity is tight.

Echelon Position and Inventory Behavior: Revisiting the Bullwhip Evidence

Mohan Gopalakrishnan, Srimathy Mohan, Piyush Shah

W.P. Carey School of Business, Arizona State University, Tempe, USA

Bullwhip effect (BWE) has been among the most prominent topics of supply chain research using different methodologies. One set of research has investigated the application of theoretical perspectives in real life data. In an interesting paper of this type, Dooley et al. (2010) used economic data to interpret the bullwhip caused because of the recession in 2007-2008. They demonstrated the bullwhip based on the data of industry as an aggregate and for the automobile industry. Based on the three years of data Dooley et.al. (2010) have suggested that all the agents at the same levels have similar response in terms of their inventory and ordering behavior.

We have three specific objectives in extending the work of Dooley et.al. (2010). First, we believe that the short time span of three years does not allow us enough data to judge the behavior of the echelons. We seek to remedy this by working with 5 years of data – from 2010 to 2014. Second, we are not sure if the results can be held valid to every individual industry cluster. We seek to advance theory for testing the behavior in multiple industry clusters. We can only generalize the results if the validity can be proved across industry clusters. While the values of the change of inventory and sales could change across clusters, the direction of the change must be consistent to prove validity. Lastly, we will examine the bullwhip in in the individual years for the aggregate and industry data to check for consistency.

We will use inventory and sales data for manufacturing industry from the US Bureau of Economic Affairs. The data provides echelon wise information for various industry segments. Based on the monthly data, the change in inventory and sales would be calculated. These values of changes will be tested for consistency. The process will be repeated to aggregate and the industry wise data.

In spite of the tremendous research, bullwhip is still a major cause for concern in the industry. The research will lead to very important insights into the echelon specific behavior that leads to bullwhip. Based on the results of our research, policies can be designed for specific echelons and mitigate the bullwhip impact. This research will also spawn further academic studies on the role of position in the supply network causing a certain bullwhip specific behavior.

Keywords: *Inventory Management, Bullwhip effect, Econometric analysis, Economic data, echelon behavior*

Reference:

Dooley, K. J., Yan, T., Mohan, S., & Gopalakrishnan, M. (2010). Inventory management and the bullwhip effect during the 2007-2009 recession: evidence from the manufacturing sector. Journal of Supply Chain Management, 46(1), 12-19

An Integrated Two-Warehouse Deteriorating Inventory Model with Shortage Backordering, Trade Credit and Decreasing Warehouse Rental

Jonas C.P. Yu

Department of Distribution Management, Takming University of Science and Technology, Taipei, Taiwan, ROC

This study develops an optimal inventory model for items with deteriorating loss and shortage backordering in a two-echelon supply chain system. It consists of one supplier and one distributor with a two-warehouse environment where the storage price of the rented warehouse decreases over time. Owners of rented warehouses can decrease the storage price when a certain time is reached as an incentive to distributors. In addition, offering a credit period stimulates suppliers' selling and reduces on-hand stock levels. Furthermore, distributor can use this credit period to reduce costs and increase profits. This study determines the optimal production lot size of both players and the number of shipments to minimize the total cost. In addition, it demonstrates that an optimal solution exists and is unique. A numerical example and sensitivity analyses are provided to illustrate the proposed model. The results of this study provide managerial insight for enterprises that use a rented warehouse to minimize costs by coordinating lot sizes.

Keywords: *two-warehouse; deteriorating items; inventory; shortage backordering; trade credit*

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