Book of Abstracts

18th International Symposium on Inventories

August 18-22, 2014
Budapest, Hungary

18th International Symposium on Inventories

Book of Abstracts
August 18-22, 2014 - Budapest, Hungary

ISBN 978-615-5270-11-6

Editor-in-chief: Attila Chikán
Technical editors: Róbert Hohol, Zsuzsanna Heiszler (Diamond Congress Ltd.)

Printed in Hungary - 2014
OOK-Press Ltd., Veszprém, Hungary
Responsible for printing: Attila Szathmáry

Table of Contents

Plenary Lectures

Performance Measures and Metrics for Sustainable Logistics

Maurice Bonney[1], Mohamad Jaber[2]

[1] *University of Nottingham, Nottingham, United Kingdom*
[2] *Ryerson University, Toronto, Canada*

The paper extends the research of Bonney and Jaber (2011), which emphasised that to examine environmental needs, inventory and logistics management systems should treat inventory as part of a wider system. In a follow-up paper, Bonney and Jaber (2013), developed an input-output activity matrix (IOAM) to represent and measure the performance of a manufacturing system, considered as a tier in a multi-tier logistics chain. The paper examines these and other studies (e.g., Bonney and Jaber, in press) relevant to developing sustainable logistics and manufacturing systems. It then considers the need for performance measurement to assess the economic and environmental impact of logistics systems and discusses the measures required to design sustainable systems.

The paper reviews the literature to identify and classify papers that study or discuss integrating environmental issues into inventory and logistics systems. The paper also considers the need for social and financial/economic issues to design sustainable systems. It examines quantitative, framework, analytical, case studies and other papers that consider performance measures and uses these to develop the performance measures and matrices needed to design sustainable supply chains and integrates these into the IOAM framework of Bonney and Jaber (2013). The paper uses the methodology for producing research agendas, described in Bonney and Jaber (in press), to develop a research agenda for sustainable inventory and logistics systems. It concludes that performance measures are essential for designing sustainable supply chains and proposes a method for producing performance measures to develop more meaningful and responsible inventory policies.

Although the research is still in its early stages, its preliminary findings suggest that a concurrent enterprise approach (CE) combined with the IOAM can represent many features of a logistics chain. These include the number of levels in the chain, material and information flows, forward and backward flows and time. The paper uses these to plan and control supply chains and to develop sustainable performance measures. The CE-IOAM helps to identify which attributes to examine including the location and condition of items, when they are there, etc. The use of a diagrammatic representation to determine system measures related to the needs of specific groups or functions, is novel. Specific groups could be customers, system operators and management. Typical functional needs include operational effectiveness, delivery performance, production needs, customer satisfaction, financial performance, quality performance, etc.

Keywords: *Sustainable logistics, performance measures, inventory, system design, research agendas*

References:

Bonney, M., Jaber, M.Y. (in press). Deriving research agendas for manufacturing and logistics systems: a methodology. International Journal of Production Economics (doi:10.1016/j.ijpe.2013.12.007)

Bonney, M., Jaber, M.Y. (2011). Environmentally responsible inventory models: non-classical models for a non-classical era. International Journal of Production Economics, 133(1), 43-53.

Bonney, M., Jaber, M.Y. (2013). Environmental and economic analysis of a production-inventory system and its attributes using an input-output Activity Matrix (IOAM), International Journal of Production Economics, 143(2), 589–597

Forecasting, Uncertainty and Managing Service Level

Robert Fildes

Department of Management Science, Lancaster Centre for Forecasting, Lancaster University, Lancaster, United Kingdom

Forecasting and inventory management were closely linked in the foundational work of R.G. Brown in the 1950s. But the link became broken and the two strands of research diverged. This paper first reviews those forecasting methods used in the management of service levels, emphasising recent innovations, both successful as well as unsupported, in particular models for multiple seasonality and intermittent demand. The focus of research linking inventory and service levels with uncertainty and forecasting are identified, showing the neglect in much of the influential research of forecasting error. The results of incorporating forecasting into service level research are illustrated with case studies in manufacturing and call centre planning. The conclusions are clear: forecasting research should focus more on the problem context faced, and for 'production/ inventory' researchers, the casual neglect of forecasting error leads to misleading conclusions as to the effectiveness of their proposed planning models.

Ordering Perishables: In Between Base Stock Policies, and Constant Order Policies

Rene Haijema[1,2], Stefan Minner[3]

[1] *TI Food and Nutrition, Wageningen, The Netherlands*

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

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

Base stock policies (BSPs) and constant order policies (COPs) are a well-studied and applied to control inventories of non-perishable products as well as inventories of perishable products. From literature, we know that a BSP may be close to optimal for some specific problem settings, whereas a COP maybe close to optimal for some other settings. In this paper we focus on the many problem settings in between. Depending on the problem parameters, BSP and COP can be improved greatly by a generalized policy: the (S,q,Q) policy. This policy is BSP with base stock level or order-up-to level S, extended with a minimal order quantity q and maximal order quantity Q. The (S,q,Q) policy can be tuned such that it mimics a BSP or a COP, or an in-between policy. When $q=0$ and $Q=S$, then the (S,q,Q) policy is a pure BSP, and when $q=Q$, the (S,q,Q) policy boils down to COP. For other values of q and Q, the policy is an in-between policy. An optimized (S,q,Q) policy performs always better or equally good as the other 4 policies, but requires tuning 3 parameters instead of only 1 for BSP or COP.

The key question to be answered in this paper is "*When to use which policy?*": more specifically, for which problem instances, can the parameters q, and/or Q be dropped from the (S,q,Q) policy, or can one even apply a BSP or a COP, without observing a significant costs increase? Therefore a numerical study is executed with 15,750 problem instances, which vary in lead time, maximal shelf life, mean demand, variance-to-mean ratio, fraction of FIFO vs LIFO demand, and the costs ratio (unit shortage vs unit outdating costs). All instances deal with stationary demand and daily ordering. For each instance, five policies are optimized by a simulation based global search: BSP, COP, (S,q), (S,Q), and (S,q,Q). One of the conclusion is that when lead time goes up, COP may perform better than BSP. In addition, we discuss approximate upper and lower bounds on parameters that define a search space for optimal parameter values. These insights help in developing new heuristics for optimizing parameter values.

Models of Socially Responsible Behaviour in Supply Chains of Food and Beverages

Danuta Kisperska-Moroń

University of Economics in Katowice, Katowice, Poland

Objectives of study: This paper aims at explaining the nature of socially responsible behavior in a supply chain. The final purpose is to indicate some differences between the models of social responsibility in supply chains of distributors and manufacturers.

Materials and Methods: The research has been based on 3 case studies of social responsibility: one of the main food distributors in the UK, the leader of the Polish beer industry and dairy products manufacturer in Poland. The source of information were study visits and professional materials published on company's websites.

The paper intends to answer the following research questions:

- **RQ1:** What are the elements of socially responsible behaviour in supply chains, and in food supply chains in particular?
- **RQ2:** What are the main Corporate Social Responsibility aspects influencing the processes in a supply chain?
- **RQ3:** Are there any standard patterns (models) of CSR in supply chains of food and beverages?

Results: The results of research cannot be considered as universal. Nevertheless, they indicate that companies with similar strong market positions adapt social responsibility concepts in their operations. In practice, models of CSR applied in supply chain of distributor differs somewhat from that one of manufacturers. Generally, distributing companies may have greater impact on their social responsibility in the whole supply chain, if only their include those aspects in their strategy.

These results provide more insight into company's practice in the CSR area and could be the outgoing point for formulation of more detailed models to be tested with dedicated surveys and statistical data analysis.

Conclusions: Research results might be of importance for decision makers and managers in supply chains, indicating which aspects of social responsibility are of special significance for successful achievement of companies' goals. It could help them to understand complex relationships within the CSR concept in a supply chain and its actual implementation.

Considering the scarcity of work examining empirically the relations of corporate social responsibility in the whole supply chain, and not just in a single firm, this study demonstrates the evidence of some regularities in that area.

Keywords: *Corporate social responsibility, socially responsible supply chains, sustainable logistics*

Inventories and the American Market for New Automobiles: Some New Results

Adam Copeland[1], George Hall[2], **Louis Maccini**[3]

[1] *Federal Reserve Bank of New York, New York, United States*

[2] *Brandeis University, Waltham, United States*

[3] *Johns Hopkins University, Baltimore, United States*

This paper constructs a model of the market for new automobiles in the U.S. On the demand side a representative household incurs shopping costs to decide on which cars to purchase and maximizes discounted utility to decide on over-all purchases of new automobiles and other consumption goods. The household faces a stochastic interest rate at which it can borrow and finance new car purchases with income and loans. On the supply-side, the model consists of a representative producer-dealer of new automobiles. This firm is a monopolistic competitor who maximizes the discounted flow of profits. The firm faces a stochastic interest rate and holds inventories to facilitate sales and production. The solution of our model determines equilibrium prices, the quantities of new cars and light trucks produced and sold, and the stock of inventories held by firms. The model is estimated via maximum likelihood techniques using monthly data on new cars and light trucks in the American market. The model is well-suited to investigating the empirical effects of changes in income, credit market conditions, interest rates and monetary policy on prices, sales, production and inventory movements in the market for new automobiles.

Analytical Insights into Two-Stage Serial Line Supply Chain Safety Stock

N. Grace Hua[1], **Sean P. Willems**[2]

[1] *Cisco Systems, Inc., San Jose, United States*

[2] *School of Management, Boston University, Boston, United States*

Effective inventory management is one of the most significant challenges facing today's global supply chains. Businesses are observing significant profitability gain by optimizing their inventory. Key safety stock inventory decisions include where, how much, and how often to replenish inventory. This paper approaches the optimal safety stock inventory in a two-stage serial line supply chain, under guaranteed-service safety stock model assumptions. We analytically show that where and how much to place safety stock depends on the cost and leadtime parameters of the supply chain. We also show changes in cost and leadtime parameters influence the optimal safety stock policy, as well as the overall supply chain safety stock cost.

Economics of Inventories

Housing Stock Management in Aging Societies

David Bogataj[1], Diego Ros-McDonnell[2], **Marija Bogataj**[3]

[1] *The European Faculty of Law, Nova Gorica, Slovenia*
[2] *Universidad Politécnica de Cartagena, Cartagena, Spain*
[3] *MEDIFAS, Šempeter pri Gorici, Slovenia*

More than 11 million homes lie empty across Europe, according to figures collated by the Guardian, of which only in Spain there are more than 3.4 million homes vacant. Accoriding to Guardian there is more than 2 million homes empty in each of France and Italy, 1.8 million in Germany and more than 700,000 in the UK. At the same time more than 4 milon of Europeans are homeless and many families and senior citisens are afraid to loos there homes because the foreclosures are pending. This figure shows that lage share of housing stock in Europe is not in use. The problem has arisen because the policy makers did not have a proper tool to balance long term supply and demand for housing. From this state of affairs there arises a question what kind of incentives should policy makers apply on housing stock management, financing and taxation to achieve a beter build environment utilisation. Hausing stock is a form of inventory of built environment and the value of housing stock represents the major part of inventories in each society, but currently it is not managed as other inventories because the management of housing stock is lacking the proper inventory management tools.

Some argue that financial crisis and housing oversupply are destroying the "community" and this destruction left behind elderly without proper care, housing, amenities and other supply. According to the World Health Organisation (WHO), physical and social environments are key determinants of whether people can remain healthy, independent and autonomous long into their old age. Creating and properly managing of age-friendly urban environments is therefore one of the most effective approaches to respond to demographic change and todays' stock of empty houses. The world's population is becoming more urbanised and older. In 2008, for the first time in history, the majority of the world's population lived in cities. It is estimated that 60% of global population will live in cities by 2030. The proportion of the global population aged 60 will double from 11% in 2006 to 22% by 2050. Each year the Globe gets a million of new seniors older than 60 years. The share of European population age 65+ in Mamber States is growing. In 50 years since 1950 till the end of century it more than doubled. Mean annual growth rate was 1.82 %. We can expect that in 2050 the percentage of people older than 65 years will be close to 173 million Europeans. It means close to 1/3 of all inhabitants. The special chalange reprepents the cohorts of 75+, which are expected to grow even faster, from 14.5 million in 1950 to over 91 million in 2050. The share of cohorts 75+ in entire European population is expected to grow to over 14 % till 2050. These demographic trends will significantely influence the housing market, therefore the communities need some new approaches to housing stock inventory management, especially because the demand for housing will change in 21th century from majority of young familys demand to increased demand of seniors with more and more impared mobility.

In the paper Competing Risk Approach is suggested to be used for modelling supply and demand for housing. It is presented how the long term stability of housing market can be achieved using Competing Risk Model. To support the long term stable and affordable, age-friendly housing market some new financial mechanisms, institutions and schemes have to be developed in Europe. Among them the major role can play the Equity Release Schemes (ERS) with the mutualy insured lonevity and value of housing stock.

Inventory Investment Trends in Old and New OECD Countries

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

[1] *Corvinus University of Budapest, Budapest, Hungary*
[2] *Hungarian Academy of Sciences, Budapest, Hungary*

The change of the political and economic system of Central and Eastern European (CEE) countries resulted in fundamental changes in the structure and operation of those economies. One of the fastest appearing and most spectacular differences between the pre- and post transition economies was experienced in the ratio of inventory investments in GDP expenditure.

This change was not at all a surprise for those who studied inventories in the CEE economies. Inventory investments' share was far (sometimes 4-5 times) higher in those economies compared to the most developed countries, tying up substantial resources of potential development. Research has revealed that this phenomenon was directly due to the market structure in these economies, namely the presence of permanent over-demand, a consequence of the shortage economy.

As a part of our ongoing research project which explores long term trends (1970 – 2012) of inventory investments in 18 OECD countries and the macroeconomic factors influencing them, we found it a fascinating research issue to explore the effects of systemic changes in six Central and Eastern European economies on inventory investments and analyze the adaption process. It was easy to show the validity of the prediction that changing market conditions will change inventory behaviour. Our paper looks beyond this fact and relates it to the macroeconomic characteristics of the countries involved. We also explore - using multivariate statistical analysis - how these developments tend to harmonize with trends in the long-time OECD countries.

Inventory Management

Global Dual Sourcing with Carbon Emissions Constraint

Emel Arikan, Johannes Fichtinger

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

Dual sourcing of goods from offshore and onshore suppliers has become a common business strategy which aims at reducing cost while maintaining customer service and responsiveness. However, growing concerns about the environmental impact of supply chains diminish the competitive advantage of offshoring. Lengthening of supply lines not only cause higher carbon emissions from transportation, but increased lead times also call for larger safety stocks which impacts the emissions related to warehousing. Moreover, in specific industries, production technologies used by low-cost offshore suppliers have significantly higher carbon intensities than their onshore competitors. Hence, offshore supplier are becoming a less attractive sourcing option not only from an economic but also from an environmental perspective. Companies trying to improve their environmental performance are forced to rethink their sourcing strategies by rebalancing volumes between the on- and offshore suppliers.

Measuring and reporting carbon emissions has becoming the rule rather than the exception in several industries. A considerable number of companies publicly state their carbon emission reduction targets. They state both long term targets, which may be addressed by strategic decisions, and short to mid-term targets such as annual improvements which should be incorporated in operational decisions.

In this study, we consider an inventory system under a carbon emission reduction target. Specifically, we analyze a multi-period dual sourcing inventory model with a constraint on emissions resulting from sourcing and warehousing. We analyze the optimal order quantities under the two well-known dual-sourcing policies, the constant order policy and the dual index policy, with a carbon constraint. We present the impact of such an environmental criterion on the optimal allocation between the offshore and onshore suppliers and provide sensitivity results based on a numerical study.

***Keywords**: dual sourcing, inventory, global supply chain, environment, carbon emissions*

Assessing Inventory Performance in the Healthcare Sector: An Italian Case Study

Anna Corinna Cagliano, Sabrina Grimaldi, Carlo Rafele

Department of Management and Production Engineering, Politecnico di Torino, Torino, Italy

In a time of limited resources healthcare institutions need to find new ways of providing patients with a high level of service while optimising costs. In this context, an appropriate control on materials becomes crucial because the associated purchasing and managing expenditures have a relevant impact on budgets.

Inventory management is a core component of supply chain (SC) activities healthcare organisations can focus on in order to improve their efficiency. In recent years, a variety of topics have been discussed by both researchers and practitioners, such as outsourcing inventory operations, adopting collaborative replenishment practices, centralising inventories, integrating RFID technology in SC processes, and applying lean and agile principles. Strategies built on such concepts can show their full benefits only if they are founded on an in-depth analysis of the current inventory performance and of the associated criticalities. However, literature lacks formal methods able to give a comprehensive yet simple understanding of how materials are managed in healthcare institutions.

In order to contribute to close the gap, the present work proposes an approach based on correlation analysis aimed at assessing the logistics performance of warehouses operating in the healthcare industry.

A literature review on manufacturing and healthcare SC processes allowed defining a set of dependence relationships representative of all the most important economic and operational aspects characterising a sound inventory and material management.

The relationships are established among variables such as the number of products, the inventory level, the number of order lines, the shipping volume, and the number of people working in the warehouse.

Then, an extensive survey relying on questionnaires and semi-structured interviews with material managers was performed and data were collected from sixty-eight warehouses serving hospitals and local healthcare agencies in Northern Italy. Based on the relationships previously identified, correlation analysis by means of Minitab software package was carried out to determine whether the studied warehouses satisfy such dependence relationships and thus to assess their performance. Results were interpreted and discussed.

The developed approach can be applied to both a group of warehouses and a single warehouse with the purpose of studying how effectively and efficiently they manage materials and identifying possible improvements.

***Keywords**: inventory management, material management, healthcare, correlation analysis, performance*

Integrated Management of Inventory and Production Systems Based on FDP

Marcos Calle[1], Pedro L. Gonzalez-R.[1], Henri Pierreval[2], Jose M. Leon[1], David Canca[1]

[1] *Higher Technical School of Engineering, University of Seville, Seville, Spain*

[2] *Institut Français de Mecanique Avancee, Campus de Clermont-Ferrand - Les Cezeaux, France*

Objectives of study: The main objective of this work is to study the influence of the integration between Inventory Management and Production Control. In this study recent hybrid production systems (based on Decoupling Point (DP) concepts) were considered.

Materials and Methods: The stochastic nature of the process makes simulation the correct tool to reach valuable results. The simulation studies have been carried out following a full factorial design of experiments (DoE). The experimental design contained three factors: a first factor consisting of 3 different degree of integration of demand forecasting and real-time inventory level; a second factor consisted of 2 order fulfilment (OF) systems based on (a) 2 fixed DP and (b) a Floating Decoupling Point (FDP); and a third factor consisted of 2 different strategy for sorting orders. Measured responses comprised customer's response time and level of finished goods inventory (FGI). Each treatment has been simulated for a variety of products of 2^k types of products (for k=2,3,4,...,13).

Results: ANOVA results show the significance of the "degree of integration of demand forecasting and real-time inventory level", providing a substantial improvement in simultaneously in 2 measured system response when the demand forecasting and levels of FGI and work in process (WIP) are combined. In contrast, the system performance worsens when the demand forecasting is just combined with levels of FGI. Also, results highlight that the best system configuration consists of a system based on the FDP where demand forecasting and levels of FGI and WIP are considered together.

Conclusions: This research shows both the opportunity for improvement and the risk of worsening produced by the integration between Inventory Management and Production Control. Finally, the study highlights that the best performance is obtained by OF systems based on the FDP and the adequate "integration of demand forecasting and real-time inventory level". Among the new avenues for further research are the inclusions of the proposed integration mechanism (a) in the existing OF systems and (b) in new strategies for prioritizing production orders.

Keywords: *inventory management, production control, floating decoupling point, simulation, design of experiments*

Company Competitiveness and Inventory Performance

Attila Chikán, Zsolt Matyusz

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

This research discusses the link between competitiveness and inventory performance of the company. Unfortunately this question is not very well addressed in the literature, though we think that inventories significantly affect the whole operations of the company (not just the various loosely related functions, like manufacturing or distribution). For the inventory-related variables we have a supply chain concept in mind, and we include variables that are importantly linked to inventories (e.g. throughput time efficiency, adequate level and mix of inventories, financial factors, top management's job related to inventories). Company competitiveness is based on variables that measure operability, ability to change and market performance. Data were acquired through the fifth round of the Competitiveness Research Project executed in Hungary in 2013 in the manufacturing industry with a sample of 136 firms. We calculated factors of competitiveness and narrowed down the sample to companies with proper data and descriptive statistics. We applied a two-step analysis: 1) cluster analysis, and the interpretation of the clusters in terms of competitiveness, then 2) ANOVA based on the clusters to identify inventory-related variables that show significant differences among clusters..

Keywords: *company competitiveness, inventory, cluster analysis*

Behavior in Single-Echelon Dual Sourcing Settings: An Experiment

Tamás Csermely[1,2], Stefan Minner[3]

[1] *Vienna University of Economics and Business, Institute for Public Sector Economics, Vienna, Austria*
[2] *University of Vienna, Doctoral School of Logistics and Operations Management, Vienna, Austria*
[3] *Logistics and Supply Chain Management, TUM School of Management, Technische Universität München, Munich, Germany*

We conducted an experiment with a single-echelon dual sourcing setting including a slow, cheap and a fast, expensive supply mode to see whether the theoretically documented advantages of dual sourcing (Ramasesh, Ord and Hayya (1993); Veeraraghavan and Scheller-Wolf (2008), etc.) have empirical support. We show that subjects have a preference for flexibility and thus overuse the fast and expensive supplier compared to the normatively optimal behavior. We document that this behavioral pattern is a result of subjects' conscious preference for less on-hand inventory and that it is driven by myopic optimization. Moreover, we prove that the observed behavior is also consistent with ex post inventory error minimizing preferences, which can be explained by the psychological cost model described by Ho, Lim, and Cui (2010), but it does not correlate with loss aversion, risk attitude, regret aversion or cognitive abilities. We conduct full parametric analysis to show that the range of psychological costs attached to overages and underages – where we see no significant difference between the actual and the theoretically optimal ratio – is relatively broad. We see that, once we take these characteristics into account, the relative overusage of the fast supply mode is not prevalent and that subjects use the fast and the slow option according to the above specified extension of normative theory. We document significant cost savings in all dual sourcing treatments compared to the single-sourcing setting even if the fast supply mode is very pricy, but even more so if it is relatively less expensive. Furthermore, we observe that the gap between the normatively achievable cost and the actual one decreases considerably by introducing an expensive dual sourcing option, whereas we see no such improvement compared to the normatively achievable costs if the fast mode is relatively inexpensive. We show that the slow supply mode is used significantly more often ceteris paribus if it is framed as an internal partner compared to when it is described as an external supplier. This can be explained by extending the psychological cost model to external suppliers. In the end, we conclude that the choice for internal versus external suppliers and also the usage of the slow and the fast supply mode are in fact driven by behavioral causes and can be explained by the extension of the normative model.

Keywords: *behavioral operations, dual sourcing, experiment, inventory modelling, ownership*

Safety Stock Policies in the Joint Economic Lot Size Model with Returnable Transport Items

Christoph H. Glock[1], Taebok Kim[2]

[1] *Department of Law and Economics, Technische Universität Darmstadt, Darmstadt, Germany*

[2] *Graduate School of Logistics, Incheon National University, Incheon, South Korea*

The literature on the joint optimization of order and production quantities had a major focus on managing the downstream flow of materials in the past. Just recently, researchers have started to analyse packaging material that is required for transporting products along the stages of a supply chain as well. So-called 'returnable transport items' (RTIs), such as pallets or containers, are a special case of packaging material. RTIs may be used more than once for transporting products, which is why both the downstream and return flows of these items need to be coordinated to permit a smooth flow of the finished item through the system. If RTI return times are stochastic, delays may occur, which can lead to stockouts at downstream stages of the supply chain. This paper studies alternative safety stock policies that help to avoid stockouts, namely I) RTI safety stocks, II) finished product safety stocks, and III) RTI and finished product safety stocks. The results of our paper indicate in which scenario which type of safety stock should be used. To the best of the authors' knowledge, this paper is the first to study the use of safety stocks in an integrated vendor-buyer supply chain with returnable transport items.

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

Take-Back Policy for Two-Echelon Rental Systems

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

University of Groningen, Groningen, The Netherlands

We consider a novel two-echelon rental system with one central depot and multiple locations. The rental system contains a fixed amount of rental items, which are pooled between locations through the depot. Locations deal with customer demands and returns. The central depot serves as a low-cost storage facility which periodically ships to locations in case of backorders and takes back stock from locations to reduce holding costs and resupply for future shipments. Costs include holding, take-back, shipment, backorder, and lost sales costs. A take-back policy specifies for each location the number of items to take-back to the central depot. This work determines cost-minimizing take-back policy.

For a single location problem (SLP) the optimal take-back policy is derived analytically. The optimal take-back policy is shown to have a threshold structure. The SLP also specifies the demand rates for which all on-hand items should be stored centrally. The threshold from the SLP provide an upper bound in the multilocation problem (MLP). The MLP is solved in small instances using the tools from Markov decision processes. The output has inspired a heuristic which is on average within 1% from optimality in small instances. For large instances with up to 100 locations, this heuristic is compared with several other policies in a simulation experiment. Results indicate that a base-stock policy at the central depot gives similar results to the heuristic in large instances.

Various insights can be derived from this work. First, the SLP provides managers a practical tool for dividing rental items between a front and back area of a location. Second, the MLP gives insight in the different types of existent take-backs. In particular, take-backs exists for holding cost reduction and for stock pooling. Finally, for large rental systems an easily implementable policy which sets a base-stock level at the central depot yields reasonable results.

Keywords: *rental system, two-echelon, central depot, take-back policy, heuristic*

Dynamic Control in Multi-Item Production/Inventory Systems

Moritz Fleischmann[1], Harold Tiemessen[2], **Geert-Jan van Houtum**[2]

[1] *University of Mannheim, Mannheim, Germany*

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

We consider a production/inventory system consisting of one production line and multiple products. Finished goods are kept in stock to serve stochastic demand. Demand is fulfilled immediately if there is an item of the requested product in stock and otherwise it is backordered and fulfilled later. The production line is modeled as a non-preemptive single server and the objective is to minimize the sum of the average inventory holding and backordering costs.

We use dynamic programming to investigate the structure of the optimal production policy in case of two products. For more than two products, We propose a new heuristic production policy. It consists of an idleness policy that determines when production is switched off and on and a scheduling policy that selects the good to produce in the latter case. The idleness policy is modeled as a vector of base stock levels, one per product. Only products with an on-hand stock level that is lower than the associated base stock level may be selected for production. Our scheduling policy is based on a rolling horizon scheme and the base stock levels are calculated via a simulation optimization procedure where we use normalized stock level histograms to steer the search.

On an extensive test bed with two products we show that the average and the maximum optimality gap over all examined problem instances are 3.4% and 11.6% respectively. This is a clear improvement compared to existing production policies. We also show that our simulation optimization method finds near-optimal base stock levels for all evaluated scheduling policies in very reasonable time. Finally, we show on a test bed with ten products that our proposed production policy outperforms existing production policies. In particular, it can achieve cost reductions up to 30% in case of heterogeneous products.

Keywords: *production/inventory systems, optimal control, dynamic scheduling, simulation optimization, heuristics*

Stochastically Capacitated Inventory Problem with Supply Backordering and Advance Capacity Information

Marko Jaksic

University of Ljubljana Faculty of Economics, Ljubljana, Slovenia

We model a periodic review, single stage inventory system of a company facing non-stationary stochastic demand by their customers and the inventory is replenished through placing orders to a stochastically capacitated supplier. Supplier's delivery performance is unreliable, where with a certain probability the order will be replenished in the following period, however, if this is not the case, supplier guarantees a full delivery in the next period. Thus, the immediate supply capacity availability has a Bernoulli distribution. In addition to this basic case, we study the setting in which the supplier quotes the supply capacity availability for a number of future periods, a so-called advance capacity information (ACI). We develop a dynamic programming model that incorporates ACI with ordering decisions. We show that it is sufficient to gather ACI up to the length of the delay of supply backorder replenishment. Under our system settings, we show that the optimal policy is of an order-up-to type, where the optimal base stock level is a function of ACI. In addition, we show the optimal base-stock level is independent of the possible backordered supply from the previous period. We carry out a numerical analysis to quantify the effect of the interplay of replenishment under supply backordering option and the value of advance capacity information. We show that the majority of the savings can be attained either due to increasing order size under information about future supply capacity unavailability and thus avoiding demand backorder costs, or order postponement in the case of favorable ACI, which leads to a decrease the inventory holding costs. We show under which conditions ACI is more valuable and give general insights to decision makers to recognize that the extent of the savings shown clearly indicates that sharing ACI should be encouraged in supply chains with unstable supply conditions.

Keywords: *inventory, stochastic models, dynamic programming, uncertain capacity, advance information*

Optimal Control of an Assemble-To-Order System with Different Review Periods

Ayse Gönül Karaarslan[1], Gudrun P. Kiesmüller[2], Ton de Kok[3]

[1] *Erasmus University Rotterdam, Rotterdam, The Netherlands*
[2] *Magdeburg University, Magdeburg, Germany*
[3] *Eindhoven University, Eindhoven, The Netherlands*

We study an assemble-to-order system with a single item assembled from two components. We assume that inventory levels are reviewed periodically and customer demand is stochastic. One of the components has a longer lead-time, higher holding cost and shorter review period compared to the other one. Such a system cannot be solved to optimality by methods in literature since the review periods are not nested. Our main objective is to find effective inventory control policies for this system.

We investigated the optimal policy for this system by using dynamic programming on a dataset, where the lead-time of the components differs by one period. First, we defined the uncertainty period of a component as the lead-time of the component plus the review period. Then, we have characterized the structure of the optimal policy, where uncertainty periods of the components are equal, and the uncertainty period of the cheap component is longer. Our analysis shows that optimal ordering decisions are quite complex. They can be state-dependent or state-independent for both components at different ordering moments.

Based on these results, we have developed three heuristic ordering policies for different conditions on the uncertainty periods of the components. These policies are state-dependent control policies, where ordering decisions are repeated at every review cycle. We show that all of the policies work well on the defined numerical setting, and we further discuss the use and effectiveness of these heuristic policies on this assemble-to-order system with more general lead-times and review periods.

Keywords: *assemble-to-order systems, dynamic programming, stochastic demand, periodic review, review periods*

Understanding the Risks and Benefits of Radio Frequency Identification (RFID) in Managing a Seasonal Product

Ozgen Karaer

Middle East Technical University, Ankara, Turkey

RFID (Radio Frequency Identification) technology offers two fundamental advantages over the barcode technology: unique identification and no line-of-sight requirement. A sophisticated RFID reader can "talk" with multiple tags through radio waves in a given instant. When compared to a typical barcode that needs to be individually scanned, RFID enables a superior and a more efficient way of object identification and communication. Through this enhanced "product visibility," RFID presents numerous implementation and benefit opportunities in retail. Achieving inventory record accuracy through RFID facilitates timely and correct shelf replenishment, which in turn is expected to increase sales. However, it is not clear where the increase in sales (or extra customers) are coming from. An immediate follow-up question is whether the increased level of sales will be sustained when all competitors adopt RFID. Additionally, it is not clear how revenue would be impacted if the retailer's total stock of the product is already limited; i.e., if it is a seasonal product with a committed buy quantity before the start of the season. To shed light on the sustainable revenue impact of RFID, here we model the RFID impact on in-season management of a retailer of a perishable (seasonal) product. Specifically, we first demonstrate how inventory record inaccuracy could hurt the revenue performance of a retailer and quantify the value of RFID in this respect. Though RFID technology has the potential to completely eliminate inventory record inaccuracy in any environment for any product type, currently, it is not a perfect technology. Here, we also study an imperfect RFID scenario and show that imperfect RFID could hurt the retailer profit performance, potentially beyond the no-RFID scenario. Thus, an imperfect technology implementation poses additional risks to the adopter firm.

Keywords: *inventory, RFID, apparel retail, perishable, seasonal*

The Effect of Material Price and Product Demand Correlations on Combined Sourcing and Inventory Management

Peter Kelle, Karl Inderfurth, Rainer Kleber

[1] *Louisiana State University, Baton Rouge, United States*
[2] *Faculty of Economics and Management, Otto-von-Guericke University Magdeburg, Germany*

Both material sourcing and inventory management are important competitiveness factors and it is a significant challenge to integrate the two areas. In sourcing, combined strategies using long-term contracts and the spot market received increasing attention recently, typically concentrating on the financial effects. However, there is a limited research on the consequence of combined sourcing considering both purchasing and inventory effects from an operations point of view. In this paper, we analyze the effect of uncertainty on the combined sourcing decision under stochastic demand and random spot market price fluctuations and exploit the benefits of forward buying in periods with low spot price levels but also keeping inventories as safety stocks. The decision on capacity reservation has to take into account the short-term utilization of each source which itself depends on the available long-term capacity. Thus, we face highly complex interactions between long-term and short-term decisions.

In our previous research, we were dealing with the specific combined sourcing problem of capacity reservation contracts and buying on the spot market and included the inventory aspects. It showed that spot market purchasing is beneficial in case of low spot market prices or insufficient reserved capacity, and the capacity reservation contract is an operational risk hedging for high spot market price incidents. However, in our previous research we did not consider price and demand correlation and intertemporal price dependencies. In finance research, the mean reverting process is a popular model for the price interdependency to describe the price changes correlated to past price and average demand. Besides including the mean reverting process, we also consider the effect of correlation between demand and price. In our model, a long-term decision is made regarding the reserved capacity level to be fixed with the long-term supplier to create sufficient protection for high spot market price incidents. Then, it has to be decided - period by period - which quantities to procure from the two sources. The overall objective is to minimize total expected cost. We model the above decision problem as a stochastic dynamic optimization problem and analyze the optimal procurement strategy by means of stochastic dynamic programming.

In this presentation, we provide a managerial analysis showing the individual and joint effects of demand and spot market price correlations on the optimal policy and provide managerial insights. The behavior of the optimal policy confirmed several previous assumptions, though some interesting and important managerial consequences arise due to the combined effect of demand and price correlations. These observations play an important role under the trend of increasing volatility and dynamic changes on the spot market but also in the customer's behavior.

Keywords: *capacity reservation, spot market, mean reverting process, stochastic dynamic programming, managerial analysis*

Re-Marshaling Operation in a Steel Plate Inventory Storage System

Eun Joo Shin[1], Jiameng Shi[2], Youn Ju Woo[1], **Kap Hwan Kim**[1]

[1] *Department of Industrial Engineering, Pusan National University, Busan, Republic of Korea*

[2] *Department of Computer Engineering, Pusan National University, Busan, Republic of Korea*

This study addresses the operation of steel plate inventory storage systems. Steel plates are stored on the floor and the cost resulting from rehandling operation is very high during the retrieval operation. In order to minimize the number of rehandles during the retrieval operation, the re-marshaling operations are performed. During the re-marshaling operation, inventories of steel plates are classified by their remaining duration of stays (RDOS) and the storage area is segregated into several zones in which each stack has steel plates with a pre-specified range of RDOS. This study addresses tactical decision rules as well as operational decision rules. Tactical decision rules include rules to classify steel plates, those to assign zones to the classified steel plates, those for finding the number of stacks of each zone for each class of steel plate inventories, and those to determine the re-marshaling time for each zone. Furthermore, this study develops operational rules to determine storage locations of steel plates in the yard during the storage process and the re-marshaling process. The operational rules attempt to minimize the total number of handing operations of steel plates while satisfying various constraints on stacking in a storage yard. The operational rules are expressed in the form of constraints to be satisfied by candidate stacks and the evaluation functions for selecting the best stack for locating a steel plate. Priorities are assigned to constraints in the decision rule. A simulation program is used to evaluate various combinations of rules during the solution procedure. The solution procedure is for finding the optimal combination of decision parameters for tactical decisions and operational decisions. The solution procedure is basically a neighborhood search algorithm and is tested by using a practical data set collected from a company supplying steel plates to a ship building company. The solution procedure is evaluated by the simulation study. Simulation experiments are conducted by changing the various input parameters in order to find the best combination of parameter values. The first experiment is to find the best parameters of tactical decision variables. The second was to find the best priorities of constraints in the operational decisions. The third one is to analyze the distribution of the number of re-handling operations in each zone. The simulation study shows that the rules in this study are robust even when the arrival pattern and the retrieval times of plates are uncertain. Numerical experiments show that the approach in this study is useful for minimizing the handling cost in steel plate inventory storage systems.

Keywords: *steel plate inventory; storage system; simulation; re-handling; re-marshaling*

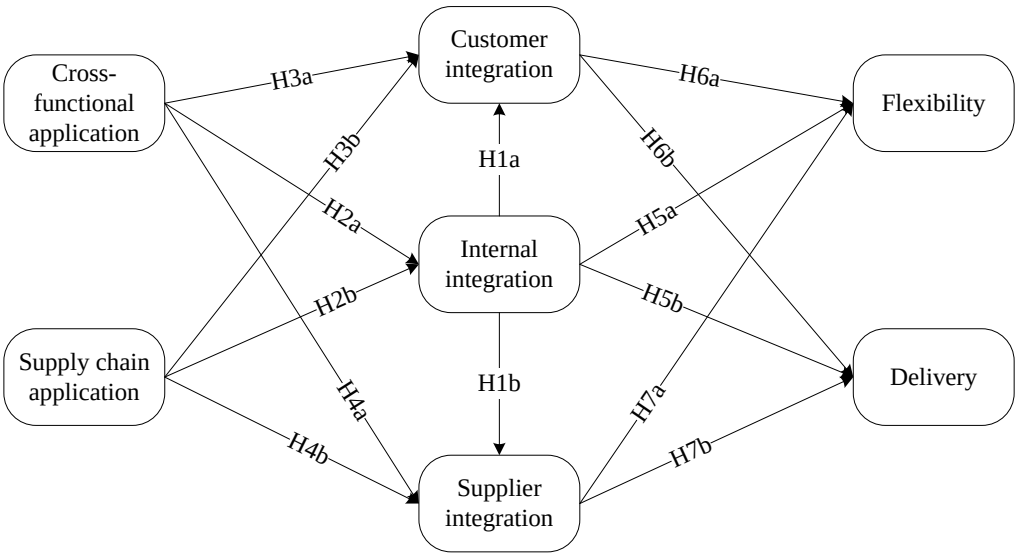
Effect of IT-enabled Supply Chain Integration on Operational Performance

Odkhishig Ganbold, **Yoshiki Matsui**

Yokohama National University, Yokohama, Japan

Many researchers have discussed a critical role that information technology (IT) plays in managing supply chain activities to enhance firm's performance. Due to uncertain direct affect of IT on supply chain performance, previous literature tried to explain how IT can improve firm's operational performance focusing on external integration with suppliers and customers. Supply chain integration (SCI) should include both intra- and inter-organization processes. The objective of this study is to find out if IT capability impacts firm's operational performance through both internal and external integrations. Our research framework is shown in Figure 1.

Figure 1
Conceptual framework

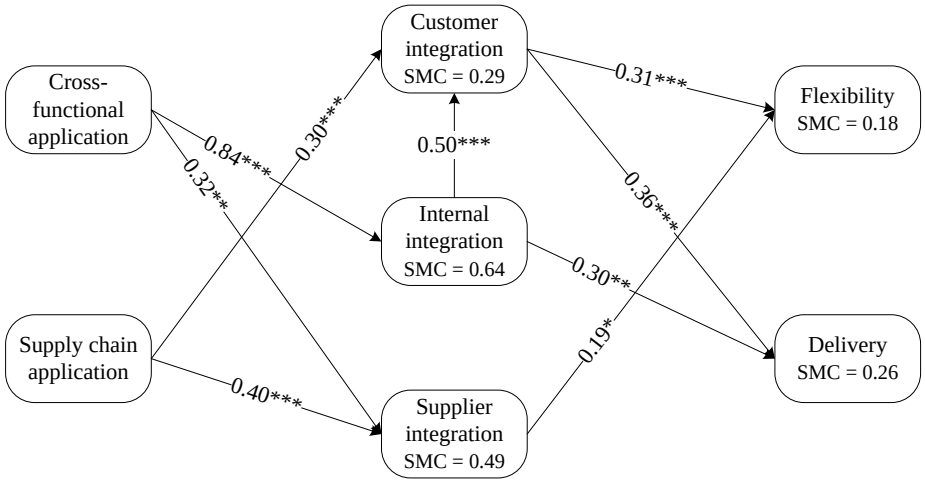


We designed a survey instrument to measure supply chain application (SCA), cross functional application (CFA), internal integration, customer and supplier integration, and operational performance. All items are measured on seven-point Likert scale. Data for this study were collected from manufacturing firms in Japan in September and October in 2013. The survey instrument was mailed to 815 manufacturing firms listed in section one of the Tokyo stock exchange. This resulted in total of 117 responses. Discarding 7 incomplete responses, the following analysis was based on a sample of 110 manufacturing firms.

Content validity of measurement instrument was confirmed through a thorough search of the literature. To test the construct validity and reliability of the instrument, we used exploratory and confirmative factory analysis and Cronbach's alpha. CR and AVE values are greater than their threshold values. The discriminant and convergent validity of all the scales was well confirmed.

The structural equation model is applied to estimate the relationship between constructs and to test the hypotheses, using AMOS 21.0. The result is shown in Figure 2.

Figure 2
Structural model results



***p < 0.001, **p < 0.01, *p < 0.05

Most of our hypotheses were supported or partially supported, indicating that IT capabilities impact operational performance through internal and external integration. Flexibility is positively influenced by customer and supplier integration, while delivery is positively impacted by customer and internal integration. Both CFA and SCA had positive impact on supplier integration, while customer integration was impacted by internal integration and SCA. Internal integration was influenced positively by CFA.

These findings contribute to the existing literature on SCM and MIS in several ways and provide some guidelines for managers to achieve better operational performance.

Keywords: *Supply chain integration; Operational performance; Information technology, Structural equation model; Empirical study*

An Approach for Estimating the Business Potentials for Operators in Local Food Supply Chain

Petri Niemi, Petra Pekkanen

Lappeenranta University of Technology, School of Industrial Management, Lappeenranta, Finland

Local, alternative and short food supply chains have attracted considerable public and political interest in recent years. As a consequence, also academic research has increasingly started to examine the possibilities and preconditions of local food systems as an alternative food supply chain. The small-scale rural food manufacturers and distributors face a traditional logistical problem: alone the logistics and distribution is expensive and access to major food distribution systems is difficult. As the customer interest and demand for local food products is growing, the business opportunities lure new operators to different roles in the local food supply chain.

Food supply chains in Europe have evolved to their present forms for centuries. The supply chains are established, not only because the total food consumption is relatively stable, but also because of chain consolidation and search for economies of scale. This means that a new, starting regional food supply chain operator has firstly a challenge to find a feasible business model to operate in the supply chain, and secondly find out whether the way of doing business has the market potential and economical prerequisites for sound business.

This paper presents a model for evaluation of the market potential and economical prerequisites of a regional food supply chain operator. The basic data in model is the national statistics on households' food expenditure. In the basic data the food consumption is categorized to hierarchic food categories and households by socio-economical groups.

In the first step, the total market potential of an alternative supply chain is evaluated by defining the market areas and estimating the market shares of different food categories on the area. In the second step the revenues and margins of the supply chain are divided to production, wholesales/distribution and retailing stages.

As an illustrative case the paper presents a business potential evaluation of a wholesaler/distributor in Southeast Finland.

***Keywords**: Local food, Supply chain, Food industry, Food retailing, Food wholesales, SME*

The Double Edged Sword of Organizational Integration: The Effect of Internal and External Information Sharing and Coordination on Firm Profit

Ryad Titah[1], Shadi Shuraida[1], **Yacine Rekik**[2]

[1] *HEC Montréal 3000, Chemin de la Côte-Sainte-Catherine, Montréal, Canada*

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

The net benefit effects of information integration on organizational performance have been rarely challenged in the IS literature. While some empirical studies have provided support for the positive effects of information integration, very few have suggested that firms may be "worse off' as a result of integration. In line with the latter view, this study considers that information integration could have either positive or negative impacts depending on the conflicting objectives of the entities involved in information integration. To investigate this view, this study examines the effect of different types of IS enabled information integrations on firm performance under supply and demand uncertainty. We consider a Supply chain composed of two stages where a supplier provides a retailer with a single product under a periodic review multi-period framework. Internal Information Integration is reflected in joint dynamic pricing and ordering strategies by the retailer's logistics and marketing units, with the objective of maximizing the expected profit under a customer service level target. External Information Integration is reflected in the supplier sharing his supply variation with the retailer, and in the retailer sharing his customer level target with the supplier. The study's findings show that Full integration (i.e., centralized decision making) results in optimal firm profitability, inventory policy and customer service level when both the supplier and the retailer share the same objectives. In contrast, when the supplier and the retailer do not share the same objectives, an "Arm's length relationship" - i.e., No integration - becomes a better alternative than Full integration, thus indicating that high integration levels are not always beneficial to the firm.

Keywords: *electronic information integration, supply chain management, internal integration, external integration, dynamic pricing, inventory policy, arm's-length relationships*

Inventory Management in Assembly To Order Environment: The Concept of Virtual Safety Stocks

Stefano Saetta, Lorenzo Tiacci

Department of Engineering, University of Perugia, Perugia, Italy

Assembly To Order (ATO) is usually adopted for quite complex and personalized items, with a deep bill of materials, and for which customers are willing to wait a certain amount of time. The 'customer decoupling point', which separates Push and Pull processes, is before the assembly processes. Thus, the procurement process, for the majority of materials, is a pull process and takes place only *after* the customer's order is arrived.

However, certain types of items, characterized by low unit variable cost and the commonality to a high number of product variants, are often managed through push processes, i.e. they are procured before the order arrives. The aim is to limit the lead time to the client and to take advantage of purchasing economies of scales.

Thus, in ATO environment, two types of item categories, and the corresponding policies, coexist:

- items with a deterministic demand over a certain time horizon, demand that is dependent from final product orders, that are usually managed through MRP-ERP systems
- items whose demand has to be considered uncertain, because they cannot be ordered after the order arrives, and that are usually managed through continuous or periodic review policies based on the Economic Order Quantity.

In this paper we analyze the management of the latter type of items. Traditional methods are based on dimensioning safety stocks to respect a determined service level, by taking into consideration the demand during the supply lead time. This kind of approach tends to overestimate safety stocks in ATO environments because does not consider that, when an order arrives, the item is not required immediately, but only when it will be assembled on the main part.

The time between the order arrival and the effective usage of the item can be viewed as a 'delivery slack' time, i.e. a time 'allowed' to the company for supplying the item without incurring in a stock-out. This time can be converted in an equivalent amount of 'virtual safety stocks', which has to be considered to correctly calculate the inventory control policy parameters. In the paper the impact of neglecting 'virtual safety' stocks on total inventory costs is evaluated on a real case study.

The same concept can be extended to other scenarios, for example when retailers provide a postponed home delivery service, such as the case of white goods of big dimensions. Usually delivery is scheduled some amount of time after the customer purchases the product. Here the 'delivery slack time' can be fixed, as in the previous case, if deliveries are scheduled always the same amount of days later, or variable, if deliveries takes place for example only in a fixed day of the week. An appropriate model to manage inventories in the latter case is also presented in the paper.

Storing and Retrieving Inventories More Efficiently by Using Multiple Cranes

Karin S. de Smidt-Destombes[1], I.F.A. Vis[2], G. Maróti[1]

[1] *VU University, Amsterdam, The Netherlands*
[2] *University of Groningen, Groningen, The Netherlands*

Inventories are often kept in warehouses, where automatic storage and retrieval systems (AS/RS) are being used. An AS/RS has the advantage that tighter aisles can be used and the space can be used more efficiently. Usually, there is one AS/RS per aisle. The aim of the study is to increase the speed of storing and retrieving inventories. Therefore, we investigate the time savings that can be reached by using multiple AS/RSs per aisle. Since the AS/RS systems are not able to pass each other, this implies that each system has its own area in the aisle, and we have to prevent the systems from clashing. We translated this problem into a linear programming problem which is applicable for any number of AS/RS more than 1. This way we can see whether it is safes time to have use more than one crane and how many cranes we should have.

Keywords: *inventory management, warehousing*

Approximate Dynamic Programming for Lateral Transshipment Problems in Multi-Location Inventory Systems

Olga Rusyaeva, Joern Meissner

Kühne Logistics University, Hamburg, Germany

Many companies allocate their inventories across multiple regions based on historical sales rates. However, the random fluctuation in customer needs, caused, for example, by weather conditions and other external factors, might cause significant deviations from the expected demand, leading to overstock in some regions and stock outs in others regions. To fix the mismatch between actual customer demand and the available stock in multiple locations in the absence of a replenishment opportunity from a central warehouse, companies often turn to lateral transshipments, e.g. the movement of stock between locations of the same echelon.

In this paper, we look at a multi-location inventory system under periodic review with multiple opportunities for proactive transshipment within one order cycle. We consider the case of no backorders. The objective of our model is to find an optimal transshipment policy that answers the question from which source to which destination how many units should be transshipped to maximize revenue. The problem is modeled using dynamic programming and can, in principal, be solved to optimality using Bellman's equation. However, the size of the state and decision spaces makes it impossible to find the optimal policy for real-size problem instances. Therefore, we use forward approximate dynamic programming to find a near-optimal transshipment policy. Our algorithm uses a concave piecewise-linear approximation of the value function and updates it using stochastic sample gradients.

Finally, we compare the performance of our transshipment policy to other proactive policies. Numerical experiments show that our proposed algorithm achieves a competitive performance against the state-of-the-art methods in the literature.

A Large-Scale Multi-Level Capacitated Lot-Sizing and Safety Stock Planning Problem

Dariush Tavaghof Gigloo, Stefan Minner

Department of TUM School of Management, Technische Universität München, Munich, Germany

We address a large-scale, multiple item, multi-level capacitated lot-sizing and safety stock planning problem (ML-CLSP) applied to a manufacturing company in the field of screw production. The planning horizon is finite and divided into time periods with dynamic and deterministic demand. The objective of the problem is to minimizing the total holding and ordering costs by taking the following constraints into account: limited storage capacities for semi- finished as well as finished goods, non-identical production resources with limited period-specific production capacity at each production level, the bill of material structures of the products, positive lead times, dynamic safety stocks of each item which are calculated based on the standard guaranteed service level approach, and the lower boundary on the production quantities.

We develop a reformulated version of a standard mixed integer linear programming (MILP) model of the problem based on a minimum cost of the network flow problem. As a basis solution approach, we present a successive, stage-wise approach where MLCLSP is decomposed into a sequence of capacitated lot-sizing problems (CLSPs) with adjusted holding and setup costs for each item at each production level.

With extensive computational tests, we show the significance and robustness of the cost saving performance as well as the computational time of solving the proposed model by alternative solution approaches.

Keywords: *Multi-level capacitated lot-sizing problem, network flow problem, mixed integer linear programming, multi-echelon safety stock optimization, period-oriented decomposition heuristic, successive approach*

SKU Service Level Specification

Aris A. Syntetos[1], M. Zied Babai[2], **Ruud H. Teunter**[3]

[1] *Cardiff University, Cardiff, United Kingdom*
[2] *Kedge Business School, Talence, France*
[3] *University of Groningen, Groningen, The Netherlands*

The fill rate is the most widely applied service level measure in industry and yet there is minimal advice available on how this should be determined on an individual Stock Keeping Unit (SKU) basis. The typical approach utilized in practice, and suggested in academic textbooks, is to set the individual fill rates equal to the targeted performance required across an entire stock base or a certain class of items (e.g., in ABC classification). In this paper it is argued that this approach is far from optimal and a simple methodology is proposed that is shown (on real life datasets) to be associated with dramatic cost reductions. In addition, the new approach is intuitive, very easy to implement and thus highly likely to be positively received by practitioners and software manufacturers.

Keywords: *inventory control; service level; fill rate; safety stock*

A Reference Process to Define Customer Order Decoupling Points in the Manufacturing Area of Small and Medium-Sized Enterprises

Dominik Thiel, Christian Siedelhofer, Ralf Elbert

Technische Universität Darmstadt, Germany

One of today's most observed challenges for small and medium-sized enterprises (SME) in the manufacturing sector is the reduction of inventories such as raw materials, WIP and finished goods.[1] An often mentioned approach to achieve lower levels of inventories is the definition of optimal customer order decoupling points (CODP).[2] However, literature of successfully applied methods or approaches concerning the position of the CODP is very scarce.[3] There are some studies developing mathematical approaches like queuing theory to define optimal CODP regarding inventory level and customer orientation.[4] Their main drawbacks are the absence of applicability and their very high level of complexity.[5] On the other hand, there exist some qualitative approaches to ascertain general aspects of positioning the CODP.[6] Those approaches allow generic conclusions but not the precise location of the CODP. Between those distinct types of approaches there can be identified the need for a quantitative method which overcomes the drawbacks of the aforementioned approaches. Hence, the objective of this paper is to develop a reference process which enables the user to define the position of the CODP in an analytical, quantitative manner so that inventories can be reduced, whereas a high service level can be maintained.

The application of this reference process was evaluated by a case study, based on real-life data, within a German SME in the metalworking industry. The method was applied in order to reduce inventories and lead times of conductors. With the iterative process each production step was analysed regarding its ability to work as a CODP by the application of the selected criteria.

The obtained case study results show the practicability as well as the effectiveness of the developed approach. Besides a reduction of complexity and inconsistency in the manufacturing area by a high degree, planned inventories could be reduced by 17%. Sales could be increased by 10% by reducing the lead time and the corresponding lost sales. Further research shall focus on the validation of the developed reference process within a general context of small and medium sized enterprises.

Keywords: *customer order decoupling point, CODP; order penetration point, OPP; location of inventories; small and medium-sized enterprises; case study research*

[1] *Rahman et al. (2013).*
[2] *Obermaier (2012); Olhager (2010).*
[3] *Olhager (2003); Sun et al. (2008); Tien (2011); Köber/ Heinecke (2012).*
[4] *Sun et al. (2008); Hajfathaliha/ Teimoury (2011); Jeong (2011); Teimoury et al. (2012).*
[5] *Rafiei/ Rabbani (2011).*
[6] *Olhager (2003); Rudberg/ Wikner (2004); Jodlbauer (2007) ; Olhager (2010); Slack et al. (2013).*

References:

Hajfathaliha, A.; Teimoury, E. (2011): Using Queuing Approach for Locating the Order Penetration Point in a Two-Echelon Supply Chain with Customer Loss. In: International Journal of Business and Management, 6 (2011) 1, S. 258 – 268.

Jeong, I.-J. (2011): A dynamic model for the optimization of decoupling point and production planning in a supply chain. In: International Journal of Production Economics, 131 (2011) 2, S. 561 – 567.

Jodlbauer, H. (2007): Produktionsoptimierung. Wertschaffende sowie kundenorientierte Planung und Steuerung, Springers Kurzlehrbücher der Wirtschaftswissenschaften. Wien 2007.

Köber, J.; Heinecke, G. (2012): Hybrid Production Strategy Between Make-to-Order and Make-to-Stock – A Case Study at a Manufacturer of Agricultural Machinery with Volatile and Seasonal Demand. In: Procedia CIRP, 3 (2012), S. 453 – 458.

Obermaier, R. (2012): German inventory to sales ratios 1971–2005—An empirical analysis of business practice. In: International Journal of Production Economics, 135 (2012) 2, S. 964 – 976.

Olhager, J. (2003): Strategic positioning of the order penetration point. In: International Journal of Production Economics, 85 (2003) 3, S. 319 – 329.

Olhager, J. (2010): The role of the customer order decoupling point in production and supply chain management. In: Computers in Industry, 61 (2010) 9, S. 863 – 868.

Rafiei, H.; Rabbani, M. (2011): Order partitioning and Order Penetration Point location in hybrid Make-To-Stock/Make-To-Order production contexts. In: Computers & Industrial Engineering, 61 (2011) 3, S. 550 – 560.

Rahman, N. A. A.; Sharif, S. M.; Esa, M. M. (2013): Lean Manufacturing Case Study with Kanban System Implementation. In: Procedia Economics and Finance, 7(2013), S. 174 – 180.

Rudberg, M.; Wikner, J. (2004): Mass customization in terms of the customer order decoupling point. In: Production Planning & Control, 15 (2004) 4, S. 445 – 458.

Slack, N.; Brandon-Jones, A.; Johnston, R. (2013): Operations management. 7. e, Harlow 2013.

Sun, X. Y.; Ji, P.; Sun, L. Y.; Wang, Y. L. (2008): Positioning multiple decoupling points in a supply network. In: International Journal of Production Economics, 113 (2008) 2, S. 943 – 956.

Teimoury, E.; Modarres, M.; Khondabi, I.; Fathi, M. (2012): A queuing approach for making decisions about order penetration point in multiechelon supply chains. In: International Journal of Advanced Manufacturing Technology, 63 (2012) 1-4, S. 359 – 372.

Tien, J. M. (2011): Manufacturing and services: From mass production to mass customization. In: Journal of Systems Science and Systems Engineering, 20 (2011) 2, S. 129 – 154.

On the Value of Imperfect Advance Demand Information for Lost-Sales Inventory Systems

Rommert Dekker[1], Geer-Jan van Houtum[2], Tarkan Tan[2], **Engin Topan**[2]

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

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

Motivated by real-life applications, we consider a lost-sales inventory system where it is possible to collect information about the quantity and timing of future demand in advance. However, this advance demand information (ADI) is imperfect because (i) it may turn out to be false, (ii) a time interval is provided for the demand occurrences rather than its exact time and (iii) there are yet customer demand occurrences for which the ADI cannot be provided. Excess inventory build up due to false ADI can be cleared at a certain clearing cost. We propose a model with a general representation of imperfect ADI to investigate both the value of (imperfect) ADI and the benefit of clearing excess stock under this setting.

Our contributions are as follows: We provide a methodological recipe on how companies can use imperfect ADI for optimal inventory planning. By using L.-convexity, with a new original state transformation, and submodularity, a partial characterization of the optimal policy is provided. Our findings indicate that the optimal policy has a complex, state-dependent structure. Also, we numerically observe that the commonly used base-stock policy is not optimal. Through an extensive numerical study, we show that use of imperfect ADI can yield substantial savings; the amount of savings is sensitive to the levels of three imperfectness aspects, i.e., timeliness, precision and sensitivity of information, as well as other system parameters. Among all, timeliness and sensitivity are found to be the most influential factors. We also find that when returns are allowed, (i) the average benefit of using the imperfect ADI is considerably higher; (ii) the amount of savings becomes less sensitive to precision. These findings indicate that returning excess stock is quite effective in coping with false ADI. Furthermore, we consider a myopic policy, which is known for its high performance in lost sales inventory systems (without ADI). Our numerical experiments indicate that the average performance of the myopic policy is generally poor and it performs well only when the return cost is low. We apply our model to case data of ASML, a manufacturer of lithography systems for the semiconductor industry which uses condition monitoring information as an ADI for spare parts demand and we show that the value of the imperfect ADI in their case is significant. The study also provides important insights, which can be useful in design and improvement of such systems.

Limits to Lean: The Fat (Inventories) We Need

József Perger[1], **Gyula Vastag**[2]

[1] *Audi Hungária Kft., Győr, Hungary*
[2] *Széchenyi University, Győr, Hungary*

This paper, using simulation models for planning small-batch production of body panels for luxury car brands on a flexible line of six work stations, explores the trade-offs between throughput rate, work-in-process (WIP) inventory levels, the storage space needed for WIP (it is a stepwise function of the number of panels in storage) and utilization levels for different product mixes and loads. The production of door and side panels (both sides), engine hoods, and mud flaps for two upscale sport car models takes place on a flexible line in a job shop environment with complex process flows and product movements. There are work-in process holding areas between stations with single or dual operations for welding, screwing, riveting, gluing and folding; the holding capacities can be expanded by moving materials back and forth between the shop floor and the warehouse. Adding WIP, on the downside, increases the labor needed for non productive tasks and ties up resources but, on the upside, by making the downstream production less susceptible of upstream production volatility, increases production throughput. The paper describes the simulation model used to find acceptable and "good" production schedules showing the "fat" (WIP levels) needed for the required production goal.

Keywords: *simulation, production planning, work-in-process inventory, job shop*

Controlling the Bullwhip Effect on Cyclic Operating Multi-Echelon Systems under Order Batching Policies

Ana Barbosa-Póvoa, **Joaquim Jorge Vicente**, Susana Relvas

CEG - IST Centre for Management Studies Instituto Superior Técnico, Lisbon, Portugal

1. Objectives of study: This paper explores the order batching influence on supply chain inventory management. The impact of order batch sizes and cyclic demands on bullwhip effect are studied considering inventory instability and order amplification. An optimization model is developed, which is solved under several real world conditions (batch, transshipment, lead-time, multi-echelon, multi-warehouse, multi-retailer, limited transportation, limited storage) so as to find the optimal solution by minimizing total operation costs.

2. Materials and Methods: A mixed integer linear model is developed to define the optimal inventory policies in a multiproduct multi-echelon supply chain where batching and transshipment policies are incorporated while accounting for the bullwhip. Bullwhip is measured through typical metrics namely, the average inventory, the inventory variance ratio, the average order, and the order rate variance ratio.

3. Results: Inventory and order metrics results suggest that the proposed optimization model can control the bullwhip effect and inventory instability in a supply chain. Cycle length has an inverse impact on the inventory variance ratio at retailers and warehouses, suggesting avoiding the use of extreme values of batch size. Order metrics suggest that batching may reduce in general order variance if using larger batches. Cycle length has no major impact in order variance ratio. Lateral transhipments decrease the inventory and order metrics values.

4. Conclusions: An optimization inventory management model is presented, which considers a supply chain subject to batch ordering and transportation, transshipment and lead-time. An experimental example and a case study are analyzed and from the results it can be concluded that the bullwhip effect does not increase without control with the order lot size increase. Thus the proposed model is able to control the inventory instability and order amplification and minimizes the bullwhip effect. As future work the impacts observed should be further studied under an uncertain demand environment.

Keywords: *supply chain inventory management; order batching; bullwhip effect; wrap-around; mixed integer linear programming*

Managing Buffer Inventory Using Control Theory

Ou Tang[1], Tore Hägglund[2], **Liu Weihua**[3]

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

[2] *Department of Automatic Control, Lund University, Lund, Sweden*

[3] *College of Management and Economics, Tianjin University, Tianjin, China*

In a process industry such as a chemical plant, production is often connected by different areas, between which buffer tanks are added. A buffer tank separates the upstream and downstream areas and it is served as an inventory point of intermediate products. Buffer management has the purpose to stabilize the operations in a continuous production. Nevertheless, in a continuous process, the production is influenced by disturbances and random environment. The actual yield often deviates from the planned production volume, due to the change of raw materials source, ambient temperature etc. Disruptions may also happen due to shortages of utility supply (such as steam, electricity, high pressure gas etc). Such random yield and disruption may force the buffer tank overflowed or run empty. In either case the production needs to be shut down, and consequently the system incurs a restart-up cost and economic losses.

In this paper, buffer management is studied by using a control theory approach. We consider the material in the buffer tank as an inventory. Such an inventory system, its control principle and problem associated are described using feedback loops. The production order is based on the averaged demand modified with the discrepancy between actual and target inventory levels (actual buffer and target buffer). Different block diagrams are presented to illustrate different control principles such as P-controller and PI-controller, as well as various flows of information. The responses are focused on two variables ORATE (production rate) and AINV (inventory volume in the buffer) which are important in buffer management and production planning, whereas the most important input signal is YIELD. In addition to the final values of the responses, we also investigate how the time to adjust inventory influences the system dynamics of ORATE and AINV under different settings. This paper concludes with some managerial insights in manage buffer tanks in such a stochastic and continuous production environment.

Keywords: *buffer inventory management, control theory, simulation, yield management*

Risk Analysis of a Two-Level Supply Chain Subject to Misplaced Inventory

Lijing Zhu[1], Chulung Lee[2]

[1] *Academy of Chinese Energy Strategy, China University of Petroleum-Beijing, Changping, Beijing, China*

[2] *School of Industrial Management Engineering and Graduate School of Management of Technology, Korea University, Seoul, South Korea*

Misplaced inventory is prevalent in retailing industries. It leads to high risks of overstock and stockout when retailers rely on inventory records to make ordering decisions. In this situation, retailers usually show a risk-averse attitude and thereby make decisions based on conservative objectives. This study incorporates the risk aversion attitude into the decision policies of a two-level supply chain, which consists of a risk-neutral supplier and a risk-averse retailer subject to misplaced inventory. The supplier makes decisions to maximize her profit, whereas the retailer adopts conditional-value-at-risk (CVaR) as his decision criterion. We investigate the optimal decisions in three cases: (i) information asymmetry about inventory errors exists; (ii) the retailer shares information about inventory errors with the supplier; and (iii) in order to reduce misplaced inventory, the supply chain deploys the Radio-Frequency Identification (RFID) technology. The benefits of information sharing and RFID implementation have been explored. We first show that the risk-averse retailer always orders less than the risk-neutral retailer no matter information is shared or not; while the supplier gets less profits if the retailer is more risk-averse. Moreover, when the retailer is subject to serious inventory errors, RFID implementation is preferred to information sharing. We also prove that the cost savings from RFID implementation are not symmetrically distributed among supply chain participants: the retailer has stronger incentives for RFID implementation compared with the supplier. Therefore, we further propose a revenue and cost sharing contract to allocate the cost savings from RFID implementation among supply chain participants. We find that a risk-averse retailer is willing to share a high portion of his revenue to the supplier, in order to obtain a low wholesale price in return.

Keywords: *misplaced inventory, risk aversion, RFID, CVaR, supply chain coordination*

Mathematical Modelling

Inventory Ordering Policies of Delayed Deteriorating Items under Trade Credits

Musa Abubakar[1], Sani Babangida[2]

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

[2] *Department of Mathematics, Ahmadu Bello University, Zaria, Kaduna, Nigeria*

Objectives of the Study: The Objective of the Study is to develop an Inventory model under trade credits with the assumption of Delayed (Non Instantaneous) Deterioration. This is a situation where Inventory Items once stocked do take some time before deterioration sets in. The study assumed that during the period before the settlement of the replenishment account, generated sales revenue is deposited in an interest bearing account with two credit periods, m_1 or m_2, for settlement of the account. If the customer settles the account in full within the period, $m_1 < m_2$, the supplier gives a cash discount; otherwise, the full payment is made within the period, m_2 but without discount. The customer is charged interest for any payment after the credit period m_2**.** The study will produce results on the particular applications of the model developed.

Materials and Methods: The model is developed on the assumption of two different demands during and after deterioration using mathematical techniques. Six different Inventory Scenarios are considered thus:

(1) $0 \le m_1 \le T_1$ (2) $T_1 < m_1 \le T$ (3) $m_1 > T$ (4) $0 \le m_2 \le T_1$ (5) $T_1 < m_2 \le T$ (6) $m_2 > T$

The total minimized Inventory costs on each of the above scenarios are computed and an Algorithm for the selection of the best permissible delay period determined. Taylor's series approximation was used to determine an approximated closed form solution of the optimal cycle length.

Results: Based on the model developed, the Total minimum Inventory Cost corresponding to the best Cycle Length for each of the above scenarios were determined. This gives the supplier the best choice on when to replenish and how much to order. The selected permissible periods m_1 or m_2

For all the above six scenarios are also determined.

Conclusions: In this Study, we develop an Inventory Ordering Policy Model for Delayed Deteriorating Items under Trade Credits. This is the situation where the supplier provides the customer with a cash discount at the rate, r when the customer pays the replenishment account at period m_1. The customer does not enjoy the cash discount when the account is settled at period m_2. Moreover, the customer is charged interest after the period m_2. The model, considers six different cases where, in each case, an approximated closed form solution of the optimal cycle length is determined using Taylor's series approximation. The algorithm for selecting the best cycle length, T and the best permissible period, m_1 or m_2 is given and various numerical examples, on the application of the model, are provided.

Keywords*: inventory; delayed deterioration; trade credits; cash discount; permissible delay in payments*

Modeling Hybrid Transshipments in Periodic Review Inventory Systems

Thomas Archibald[1], Kevin Glazebrook[2], Colin Paterson[2], Sandra Rauscher[2]

[1] *University of Edinburgh Business School, Edinburgh, United Kingdom*
[2] *Lancaster University Management School, Lancaster, United Kingdom*

Objectives: The research considers the management of a network of customer-facing, stock-holding locations. Transshipments are a means to redistribute inventory in such a network to better meet demand. Models of transshipments generally assume either a reactive (i.e. to meet existing shortages) or proactive (i.e. to meet anticipated future shortages) approach. In contrast this research uses hybrid transshipments designed to meet existing shortages and redistribute inventory to reduce the risk of future shortages. Reactive and hybrid transshipments are both prompted by the occurrence of demand that cannot be met from local stock. However a hybrid transshipment can move more items than are needed to meet the shortage. In this way, a hybrid transshipment has characteristics of both reactive and proactive transshipments. The aim of this research is to establish the effectiveness of hybrid transshipments for periodic review systems.

Method: The model assumes locations are simultaneously replenished according to a base-stock policy. Demand at locations is modelled by independent Poisson processes. When demand arises at a location that cannot be met from local stock, the excess demand can be backordered or met via a hybrid transshipment from a single location with stock on-hand. The aim is to minimize the expected cost (comprised of holding, backorder and transshipment costs) of meeting demand. There are three elements to the approach adopted. Firstly an exact expression for the expected cost until the next system replenishment under the assumption of no further transshipment is developed. Secondly a heuristic based on a dynamic programming policy improvement step is proposed. Finally for comparison, a lower bound on the expected cost of meeting demand is constructed.

Results: Experiments with test problems show that the gap between actual cost and the lower bound is 1.5-3.5% for the proposed heuristic compared to 7-14% for complete pooling. This improvement is due to fewer transshipments (approx. one third) of larger size (approx. 3 times).

Conclusions: Transshipment cost is often dominated by factors (e.g. time and distance) that are independent of transshipment size. The research shows that the hybrid transshipment is extremely effective in such cases. By advocating fewer, larger transshipments, the approach results not only in substantial cost savings, but also a greener policy.

Keywords: *periodic review, transshipment, dynamic programming, heuristics, stochastic demand*

Base-stock Policies for Lost-Sales Models: Aggregation and Asymptotics

Joachim Arts[1], Retsef Levi[2], Geert-Jan van Houtum[1], Bert Zwart[3]

[1] *Eindhoven University of Technology, Eindhoven, The Netherlands*
[2] *MIT, Cambridge, United States*
[3] *CWI, Amsterdam, The Netherlands*

This paper considers the optimization of the base-stock level for the classical periodic review lost-sales inventory system. The optimal policy for this system is not fully understood and computationally expensive to obtain. Base-stock policies for this system are asymptotically optimal as lost-sales costs approach infinity, easy to implement and prevalent in practice. Unfortunately, the state space needed to evaluate a base-stock policy exactly grows exponentially in both the lead time and the base-stock level. We show that the dynamics of this system can be aggregated into a one-dimensional state space description that grows linearly in the base-stock level only by taking a non-traditional view of the dynamics. We provide asymptotics for the transition probabilities within this single dimensional state space and show that these asymptotics have good convergence properties that are independent of the lead time under mild conditions on the demand distribution. Furthermore, we show that these asymptotics satisfy a certain flow conservation property. These results lead to a new and computationally efficient heuristic to set base-stock levels in lost-sales systems. In a numerical study we demonstrate that this approach performs better than existing heuristics with an average gap with the best base-stock policy of 0.01\% across a large test-bed.

Improving Multi-Echelon Service Part Allocation for Energy Networks at a Utility Company

Diederick van den Berg[1], Matthieu van der Heijden[2], Peter Schuur[2]

[1] *Alliander N.V., Arnhem The Netherlands*

[2] *University of Twente, Twente, The Netherlands*

We study a multi-item, two-echelon, continuous-review inventory problem at a Dutch utility company. We develop a model that optimizes the quantities of spare parts and their allocation in the multi-echelon network under an aggregate waiting time restriction. For each Stock Keeping unit (SKU), the stocking strategy should be selected out of four options: stocking at a central location in the network, stocking at the supplier, and stocking at both a central stockpoint and local stockpoints where we can choose between a small or a large set of local stockpoints. The large set of local stockpoints contains, next to manned warehouses, unmanned stockpoints as well.

Compared to traditional spare part optimization models like VARI-METRIC, we face some complications. First, demand that cannot be satisfied from stock on hand should be satisfied by emergency orders from a location upstream in the network. Backordering is no option, as downtime of the energy network should be avoided as much as possible. Second, the spare parts assortment consists of a large variety of spare parts and not just slow movers. As a consequence, one-for-one replenishment is not the best choice for all parts. This yields a multi-item, multi-echelon spare part optimization problem with emergency shipments in case of stockout and with batching for regular replenishment orders at the central depot.

We use column generation as basic technique to solve this problem, with as single-item building blocks some models from literature that we extended where necessary. In particular, we need a two-echelon model with emergency shipments and batch size larger than one at the central warehouse for regular replenishment orders. We separately test this new building block by comparison to results from discrete event simulation.

Finally, we encountered that the company prefers simple rules of thumb over a complex optimization model. Even though such simplicity is hard to accomplish for a complex problem, we study the options to derive simple classification rules from the solution of out multi-item, multi-echelon spare part optimization problem using statistical techniques (a.o. ordinal regression).

We apply our models and techniques on a case study using data that we retrieved from the utility company. We find using our approach that promising gains are feasible for the company.

Keywords: *spare part, inventory, multi echelon, lost sales, batching*

Lead Time and Market Perturbations at the Interest Rate Variation as the Risk Drivers in a Global Supply Chain

David Bogataj, **Marija Bogataj**

Mediterranean Institute for Advanced Studies, Šempeter pri Gorici, Slovenia

The focus of this paper is the risk management of total supply chains through identifying risk drivers like lead time perturbations. Such perturbations could appear in products flow, information flow or financial flows. This delays perturbation that could appear simultaneously also with perturbations of market, it means in prices and demand, and mitigating supply chain risk using Net Present Value (*NPV*) approach in Extended Material Requirements Planning (Extended MRP) models - EMRP. Any risk driver that is likely to disrupt the procurement, production, transportation, warehousing, delivery or financing of a good or service constitutes a realisation of supply chain risk. Risk drivers often appear simultaneously. When supply chains were primarily domestic, financial institutions could more easily monitor the activities and supply chain flows of their clients. There was closer communication and interaction between suppliers and their customers. By increasing the distances between pairs of activity cells belonging to global supply chains, visibility has become lower, and vulnerability has increased. Supply chain risks have been characterised as circumstances in which "unexpected events might disrupt the flow of materials on their journey from initial suppliers to final customers" (Waters, 2007). A sudden liquidity problem in an activity cell in a supply chain that would disrupt material flows could constitute such an event. Such disruptions occurred frequently during the 2008-2009 period corresponding to the 2008 financial crisis (Yorulmazer, 2014). These events continue to influence disruptions of material flows in some supply chains today. Therefore also Forbes reported the conclusions from Davos, where the participants concluded that the severity and frequency of supply chain disruptions seems to be increasing and also that "To maintain effectiveness, supply chain managers can arrange to share strategic stocks, or to enter into joint supply agreements. They can also pre-arrange ways to access critical stocks such as emergency fuel and medical supplies" (Culp, 2013). A solution is in sufficient provision of material and financial resources to prevent the ruin of the chain. The simulation model is developed to evaluate interactions among these risk drivers. It shows how strong could be the impact of uncertainty in lead times on resilience of the chain.

References:

1. *Culp, S. 2013. Supply Chain Disruption A Major Threat To Business. Forbes 2/15/2013 http://www.forbes.com/sites/steveculp/2013/02/15/supply-chain-disruption-a-major-threat-to-business.*
2. *Waters, D., 2007. Supply Chain Risk Management: Vulnerability and Resilience in Logistics, Philadelphia, PA, Kogan Page.*
3. *5Yorulmazer, T. 2014. Case Studies on Disruptions during the Crisis. Economic Policy Review, Federal Reserve Bank of New York. < http://www.newyorkfed.org/research/epr/2014/1402yor1.pdf>*

A Continuous Review, One-Warehouse Multi-Retailer Problem with Non-Homogeneous Poisson Demand

Christian Bohner, Stefan Minner

TUM School of Management, Technische Universität München, Munich, Germany

Rapid technical evolution evidently causes shorter product lifecycles in the computer and electronics industry, i.e. demand for these products changes within little time. In addition, demands for many products are subject to trends or seasonalities. Capturing these time dependencies of demand requires use of non-stationary inventory models. For lumpy demands, which, e.g., occur for spare parts for electronic devices, demand behavior is often modeled as a Poisson process.

For homogeneous Poisson processes, the optimal inventory policy is known to be a base-stock policy as long as orders do not cross. In this stationary setting, the derivation of optimal base-stock parameters for a one-warehouse multi-retailer system is well-known.

We extend the one-warehouse multi-retailer problem to the case of non-homogeneous Poisson demand varying over time. We apply the unit-tracking approach, where expected costs of each unit yield the total expected costs of the system that we wish to minimize. We find a decision rule and determine optimal base-stock levels at the warehouse and the retailers at each point in time. The optimal base-stock levels are found to be time-dependent step functions. For these step functions, we find two effects: Steps are triggered by either a quantity effect, i.e. total system stock is raised or reduced, or by an allocation effect, i.e. the system stock does not change but the stock allocation changes towards centralization or decentralization. These two effects are introduced in detail and exposed in a numerical study.

At first glance, it might seem reasonable to find base-stock levels for the non-stationary problem through a rolling horizon approach, i.e. by repeatedly applying the stationary solution approach to all points in time. However, as we use simulation to compare our optimal base-stock levels to the ones obtained by the rolling horizon approach, we find that the latter performs significantly worse. Nevertheless, we prove that applying a time shift to the rolling horizon solution yields the retailers' optimal solution for one class of non-homogeneous Poisson processes. In general, this procedure serves as a simple heuristic for both warehouse and retailers.

Keywords: *multi-echelon, non-stationary, inventory, base-stock policy, decision rule*

Chance-Constrained Programming for One Level Assembly System under Random Lead Times

Valeria Borodin[1], Faicel Hnaien[1], Nacima Labadie[1], Alexandre Dolgui[2]

[1] *Laboratory of Industrial Systems Optimization (LOSI), Charles Delaunay Institute, University of Technology of Troyes (UTT), ICD-LOSI, Troyes, France*

[2] *Ecole Nationale Superieure des Mines, FAYOL-EMSE, CNRS UMR, Saint-Etienne, France*

In this study, we consider the inventory control for one level assembly system under uncertainty on lead times.

The lead times can be uncertain for different reasons such as machine breakdowns, transport delays, strikes, etc. The finished product needs several components for the assembly operation for one level assembly system. We consider the case of discrete distributions to be closer to the usual assumption of MRP softwares, where the lead time is expressed as the number of periods. Typically, this is an inventory control problem where the objective is to minimize the component holding and backlog costs for the finished product due to the uncertainty of lead times. Indeed, as the finished product is assembled by using several types of components, the assembly is stopped even if a single type of component is delayed. The other components are stored between their arrival and the arrival of the latest component. Notwithstanding its non-linearity, a joint chance constrained programming model is proposed and solved via an equivalent mixed-integer linear reformulation jointly with scenario based approaches. Besides the expected optimal solution, these approaches offer alternative solutions with desired confidence level for large scale problem instances.

Keywords: *assembly systems, random lead time, joint chance-constrained programming, scenario based approach*

Exact Expressions for Key Performance Indicators for the Periodic Review Inventory System with Stochastic Demand and Ordering in Integer Multiples of a Base Lot Size

Karel van Donselaar, Rob Broekmeulen

Eindhoven University of Technology, Eindhoven, The Netherlands

In our paper exact formulas are derived for several Key Performance Indicators (KPI's) for the periodic review inventory system with stochastic demand and ordering in (integer multiples of) fixed lot sizes, also known as the (R,s,nQ)-system. The KPI's include the fill rate, discrete ready rate, the expected inventory on hand, the expected number of backorders, the expected number of order lines and the expected order size. We will derive general expressions for these KPI's for both discrete and continuous demand distributions. For the special case of gamma and normal distributed demand explicit exact expressions are derived which can easily be implemented in Excel. Based on these results we developed an easy-to-use Excel tool which is used both in bachelor and master level courses. The theoretical results derived in this paper in combination with the user-friendly software tool developed enable students to get exact results for inventory systems which are highly relevant in practice and for which standard textbooks only provide approximations.

Optimal Reordering Rule in Franchised Convenience Store

Hiroaki Fujikawa, Kouhei Keino

Tokyo University of Science, Tokyo, Japan

Franchised convenience stores lose clients due to the shortage of commodities on the shelf. In general, most of the retailers 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 life of the fresh food commodities such as sandwiches and rice-balls is getting shorter and shorter. The franchised convenience store have two specific constrains of operation. One is that over expire-dated products are prohibited to buy. The other is near expired-dated commodities are not discounted. Namely, the over expire-dated commodities should be disposed without selling discounted price. This is very unprofitable operation for retailers. Managers of the franchised convenience stores usually deal this problem with only decision of reordering quantity of each commodity without shortage and disposal. This way, reorder rule for the franchised convenience stores is very important tool to keep their stock level optimal. Also from the environmental view point, retailers should decrease disposal quantity as possible as they can. Taking a sample franchised convenience store, we estimate store master's reordering method with their actual POS data which traces how many commodities ordered, how many commodities dumped and how many commodities sold in each period. Newsvendor's model is famous for these daily products. But newsvendor's model cannot give appropriate results toward sample store. POS data does not include real inventory data. Therefore we have to estimate inventory quantity from the automatically taken POS data. Then we could find the gap between in-bound minus out-bound quantity of POS data and estimated inventory quantity. That gap must be the number of shoplifting. After all we propose heuristic ordering method. By using proposed reordering rule, we can decrease reordering quantity by 12% and inventory quantity by 9% in comparison with store master's method.

Keywords: *franchised convenience store, expiration date, reordering, disposed product, newsvendor's model*

Comparison of Two Methods for Customer Differentiation

Sven Axsäter[1], **Adriana Gabor**[2], Guangyuan Yang[2]

[1] *Lund University, Lund, Sweden*
[2] *Erasmus University Rotterdam, Rotterdam, The Netherlands*

In response to customer specific time guarantee requirements, service providers can offer differentiated services. However, conventional customer differentiation methods often lead to high holding costs and may have some practical drawbacks. In this paper we compare two customer differentiation policies: stock reservation and pipeline stock priority for high priority customers. We derive exact analytical expressions of the waiting time distribution of both types of customers for a stock reservation policy. We then provide accurate approximation methods for a pipeline stock priority policy.

Via extensive numerical experiments, we found that, in cases with low arrival rate and sufficient available stock, the pipeline priority policy offers comparable service levels to high priority customers as the stock reservation policy, while offering a higher service level to the low priority customers.

When the arrival rate of the low priority customers is relatively high and stock is scarce, the stock reservation policy insures a higher service level for the high priority customers, at the expense of the service level for the low priority ones. The numerical results indicate that it is better to use the stock reservation policy when high priority customers are much more valuable than the low priority customers, and the service level offered to the latter ones is not of importance; on the other hand, when one desires to offer good service levels to both types of customers given differentiated response times, the pipeline priority policy is a better option.

Keywords: *textitservice differentiation; priority demand classes*

Information System Based Optimal Replenishment Policy for Time-Varying Deterministic Demand under Vendor Managed Inventory

Kannan Govindan[1], Devika Kannan[2]

[1] *Department of Business and Economics, University of Southern Denmark, Odense, Denmark*

[2] *Department of Mechanical and Manufacturing Engineering, Aalborg University, Copenhagen, Denmark*

The paper focus on evaluating the performance of the adjusted Silver-Meal heuristic replenishment policy, in a centralized organization, for two environments namely (a) traditional supply chain and (b) Vendor managed inventory (VMI) supply chain. The mathematical model is developed to evaluate the stable or mature products under time varying deterministic demand pattern. The most relevant parameters to be considered for a successful replenishment policy are identified, characterized and differentiated for two cases: traditional supply chain and VMI supply chain. At the end, the proposed model is validated with a numerical application based on the data gathered from the pharmaceutical industry. The conclusion of the application shows that strong savings from the replenishment strategy can be achieved when centralized decision making such as VMI supply chain substitutes a traditional supply chain.

Keywords: *time-varying deterministic demand; adjusted Silver-Meal heuristic for a traditional supply chain; adjusted Silver-Meal heuristic for a VMI supply chain; pharmaceutical industry*

Introducing Opportunities for Lost Sales and Partial Backordering into Cumulative Staircase Considerations for Dynamic Lotsizing

Dilay Çelebi[1], **Robert W. Grubbström**[2]

[1] *Department of Management Engineering, Faculty of Management, Istanbul Technical University, Istanbul, Turkey*

[2] *Linköping Institute of Technology, Linköping, Sweden*

Dynamic lotsizing considers determining the optimal size of batch quantities and their timing, when requirements are distributed over time as different discrete demand events. In the standard formulation, no shortages are allowed and replenishments take place instantaneously.

In previous papers, using cumulate staircase/ramp representations for demand and production, the dynamic lotsizing problem has been analysed for cases of a finite production rate, with no backordering or complete backordering[1]. This analysis has included applying the Net Present Value principle, and the Average Cost approach as an approximation, for the objective function.

In the current paper, we continue these considerations by allowing for the opportunity that a given percentage of shortages become lost sales. Other additional extensions to previous theory are taking (i) out-of-pocket inventory holding costs and (ii) bad-will consequences into consideration (aside of capital cost consequences from out-payments of production costs and delayed in-payments from sales).

Keywords: *dynamic lotsizing, backlog, lost sales, net present value, economic order quantity, EOQ, economic production quantity, EPQ*

References:

[1]Grubbström, R.W., Dynamic lotsizing with a finite production rate, doi: 10.1016/j.ijpe.2012.12.009, Grubbström, R.W., Cumulative staircase considerations for dynamic lotsizing when backlogging is allowed, doi: 10.1016/j.ijpe.2013.05.027.

Optimal Purchase Quantities under Correlated Demand, Price and Yield Uncertainty

Refik Gullu, Elif Cetin

Industrial Engineering Department, Bogazici University, Istanbul, Turkey

In this talk we consider a system where a commodity needs to be purchased for satisfying a future uncertain demand. Assuming that the commodity prices randomly fluctuate over time, one commonly applied strategy is to enter a forward contract, for a certain amount to be delivered at the time of the demand, by paying a forward price to be determined today. If the realized demand happens to be more than the amount delivered, then the shortfall is satisfied from the spot market. If, on the other hand, if the realized demand is less than the amount delivered, then the excess amount is sold at the spot market. Moreover, although the forward purchase quantity is specified in the contract, the supplier may not be able to deliver the exact amount due to fluctuations in the yield, or due to a quality problem in the delivered batch.

This is the risk associated with the supply. **The objective in this study** is to find the optimal purchase quantity that will minimize the expected cost of the system by considering uncertainties in the demand, price and yield.

As a modeling method, we represent demand and price quantities as jointly distributed lognormal random variables. The yield (as a percentage of the ordered quantity) is modeled as a truncated lognormal random variable, with possible correlation with the price and demand. We derive expression for the expected cost of the system, and obtain nearly closed-form solutions for the optimal purchase quantity.

We design a computational study in order to understand the impact of the yield uncertainty and the impact of its correlation with other variables. Namely, we try to answer the following questions. How much additional cost is incurred (as a percentage) by ignoring the supply risk in the purchasing decision? Is there a significant cost-wise improvement of identifying the correlation between price and yield variables. **Our initial results** reveal that, depending on other parameters in the system, the cost benefit of a better modeling of yield uncertainty can be substantial.

In conclusion, our model provides original analytical findings, together with important managerial insight for a system with demand and price uncertainty and operating under supply risk.

Keywords: *supply risk, yield uncertainty, forward contract, optimal order quantity, newsvendor model*

An Economic Order Quantity Model for Items that are Both Ameliorating and Deteriorating with Linear Inventory Level Dependent Demand and Fixed Partial Backlogging Rate

Yusuf I. Gwanda[1], B. Sani[2]

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

[2] *Department of Mathematics, Ahmadu Bello University, Zaria, Kaduna-Nigeria*

Objective of the Study: Our objective is to develop an economic order quantity model for items that are simultaneously ameliorating and deteriorating where the demand rate is a function of the on-hand inventory with shortages. We also endeavor, using the model to determine the optimum minimum cost per unit time TVC (T_1^*, T^*) and optimal order quantity I^*.

Materials and Methods: The model is developed on the assumption that the demand is linearly dependent on stock level. The demand rate $D(t)$ at time t is assumed to be of the form $D[(t)] = \rho + \sigma I(t)$, where ρ is a positive constant, σ is the stock dependent demand rate parameter, $0 < \sigma < 1$, and $I(t)$ is the non-negative inventory level at time t.

The total minimized inventory cost which is a function of two variables, T_1 and T which respectively represent time horizon for the positive and negative inventory was determined; the cost was then expressed in single variable T_1 which can be solved using suitable analytical method. The solution for T_1 was used to obtain an expression for T and these solutions T_1* and T* jointly make the optimal solution for expressions in terms of T_1 and T provided $\frac{\partial^2}{\partial T^2}(TVC(T^*, T_1^*)) > 0$ and $\det[H_m(T^*, T_1^*)] > 0$, where $\det[H_m(T^*, T_1^*)]$ is the determinant of the Hessian matrix given by

$$H_m(T, T_1) = \begin{bmatrix} \frac{\partial^2}{\partial T^2}(TVC(T^*, T_1^*)) & \frac{\partial^2}{\partial T \partial T_1}(TVC(T^*, T_1^*)) \\ \frac{\partial^2}{\partial T_1 \partial T}(TVC(T^*, T_1^*)) & \frac{\partial^2}{\partial T_1^2}(TVC(T^*, T_1^*)) \end{bmatrix}$$

are satisfied,

Results: From the developed model, the optimum ordering quantity which minimizes the overall inventory costs was determined. The model also calculates the optimum minimum cost per unit time and the optimal order quantity. Numerical examples were given and sensitivity analysis was carried out on one of the examples to see the effects of parameter changes on the decision variables.

Conclusion: In a nutshell this paper studied an economic order quantity model for both ameliorating and deteriorating items in which the demand rate is constant. The model determines the optimum quantity to order while keeping the relevant inventory costs minimum. Numerical examples are given to illustrate the developed model and sensitivity analysis carried out on the results obtained from one of the examples.

Keywords: *deteriorating inventory, ameliorating inventory, EOQ model, stock-dependent demand, partial backlogging*

Optimizing the Speed of Quality Checking in EPQ Models with Defective Items

Zsuzsanna Hauck

University of Pécs, Pécs, Hungary

Many companies check the quality of each item before they would sell them. In our Economic Production Quantity models, we assume that good quality items are sold on a daily basis while defective ones leave the warehouse together, at the end of the screening period. Shortages may occur, depending on the level of demand, the speed of quality checking, and the proportion of defective items in a lot.

The proportion of defective items is a random variable, and we consider two different approaches of its behavior. In the first type of models, after the first cycle, the percentage of imperfect items remains at the same level in each period. We compare the properties and related results of this model of connecting cycles to those where cycles are independent from each other. In the latter case, the state of the system may change in consecutive periods.

Speed of quality checking is a decision variable in both types of models, and we consider general and specific screening cost functions. When no shortages occur, speeding up the screening process reduces holding costs when the proportion of defections is large. When shortages occur, an enhanced speed reduces backlogging costs, it makes holding costs remain the same, while setup costs increase due to shortened cycles. In the paper, we provide methods for finding the optimal speed of screening as well as the optimal lot size.

Keywords: *lot sizing, speed of quality checking, backlog, optimization*

Generalizations of Inventory Policies with Two Supply Sources

Mustafa Hekimoglu, Alan Scheller-Wolf

Erasmus University Rotterdam, Rotterdam, The Netherlands

Inventory control policies with multiple suppliers have been studied for fifty years. In the literature a simple dual index optimal policy structure has only shown for problem settings in which there is one period difference between the lead times of two suppliers who provide identical products. In this study, we propose two different generalizations of this problem: In our first model, we consider a supplier whose default risk is dependent on the order frequency of the buyer operating along with a spot market. In this case we show that a modified dual index policy is optimal under a single condition on the cost after a supplier default. In our second model, we consider the existence of a quality difference between products from two suppliers whose lead times differ by one time unit. A natural outcome of this quality difference is demand substitution between products in different qualities. Under a mild sufficient condition, we prove that the cost function for this model is pseudoconvex, which leads again to the optimality of dual index policy.

A Simple Model for Emergency Orders in the Periodic-Review Inventory System with Fixed Ordering Costs and Compound Poisson Demand

Søren G. Johansen, Anders Thorstenson

Department of Mathematics, Aarhus University, Aarhus, Denmark

Emergency orders have shorter lead times but incur extra costs compared to normal orders. We present a discrete-time Markov model where normal orders are issued according to a reorder point policy with a fixed order quantity, whereas emergency orders are controlled by a fixed optimized reorder point policy with a target stock level. A rapid search algorithm is used to find and evaluate the policy that minimizes the long-run average cost per review period. In addition to fixed and variable costs for normal and emergency orders our model includes linear holding and backorder costs. The review period is of any given length. Neither the normal order nor the emergency order lead time are required to be integer multiples of the review period. We benchmark our simple policy with a more complex dynamic policy developed by Johansen and Thorstenson (2014). For cases with volatile demand, we report numerical results that show only moderate cost penalties from using the simple policy compared to using the dynamic policy for emergency orders.

Multi-Step Switching Policy for Dynamic Pooling of Make-To-Stock and Make-To-Order operations

Shohei Kanda, Katsuhiko Takahashi, Katsumi Morikawa, Daisuke Hirotani

Production Systems Engineering Laboratory, Division of Electrical, Systems and Mathematical Engineering, Institute of Engineering, Hiroshima University, Hiroshima, Japan

Objective of study: Generally, production systems are classified into two types: make-to-stock (MTS) and make-to-order (MTO). Recently, a dynamic MTS-MTO hybrid system which can dynamically switch flexible machines between MTS and MTO productsion is developed to improve the productivity of production system (Zhang et al.[1]). However, in the dynamic MTS-MTO hybrid system, the flexible machines are switched all together, and some system performances are slipped than static system. Therefore, for improving the system performance in dynamic MTS-MTO hybrid system, we propose a switching policy that flexible machines are switched in stepwise and analyze the effectiveness of the switching policy.

Materials and Methods: In this paper, we introduce the "switching step-size" $\delta = (\delta_0, \delta_1)$ where δ_0 and δ_1 are non-negative integer into switching policy for dynamic MTS-MTO hybrid system. The policy with the switching step-size is called as multi-step switching policy. Three policies are considered in this system: either δ_0 or δ_1 is positive, and both of δ_0 and δ_1 are positive. These switching policies are called policy 1, 2 and 3 in sequence. The effectiveness of each policy is analyzed based on Markov analysis with state transition diagram. In the Markov analysis, the performance measures of the system: such as system operating cost, average MTO queue length, are calculated by using the derived steady state probability of each state.

Results: The results of analysis show that the effective proposal policy depends on the situation, especially the condition of MTS and MTO demand. In case of more demand for MTS machines than MTO machines, we can reduce system operating cost and average MTO queue length with policy 2. On the other hand, when MTO machines are demanded much more than MTS machines, all performance measures of policies 1 and 3 can be improved than the previous policy. However, under all situations, average MTO queue length of proposed policies is always shorter than previous policy.

Conclusion: In this paper, we proposed multi-step switching policy and investigate the effectiveness of the proposed switching step-size in the dynamic MTS-MTO hybrid system. The results of Markov analysis show that the system performance such as system operating cost and average MTO queue length can be improved, and it can be claimed that proposed multi-step switching policy is effective to the performance of switching policy in the dynamic MTS-MTO hybrid system.

Keywords: *Make-to-stock, Make-to-order, Switching step-size, Hybrid machine, Markov analysis*

References:

[1]Zhang, Z.G., Kim, I., Springer, M., Cai, G., Yu, Y., 2013. Dynamic pooling of make-to-stock and make-to-order operations. International Journal of Production Economics 144 (1), 44-56

Incorporating an Operational Layer into the Guaranteed-Service Inventory Optimization Approach

Daniel Dittmar[1], **Steffen T. Klosterhalfen**[2]

[1] *Schumpeter School of Business and Economics, University of Wuppertal, Wuppertal, Germany*

[2] *BASF SE, GVM/S, Ludwigshafen, Germany*

The existing multi-echelon inventory optimization literature distinguishes between two approaches: guaranteed-service (GS) and stochastic-service (SS) models. The SS approach assumes that safety stock is the only buffer against demand uncertainty in a supply chain. Based on this assumption the system behavior is modeled in an exact mathematical way at an operational level of detail: material shortages at upstream stages cause delivery delays to downstream stages. This makes the approach easily comprehensible and rather indisputable among inventory researchers. The GS approach, on the other hand, assumes that the safety stock at each stage is designed to cover demand variability up to a certain level only. Excess demand is dealt with by additional uncertainty countermeasures, e.g., accelerated production. Instead of explicitly modeling these additional measures, the existing GS contributions incorporate this operating flexibility simply via an assumption: the demand process is bounded. The demand bound expresses the maximum level to be covered by safety stock. Hence, operational details regarding the handling of excess demand through the flexibility measure are neglected in the mathematical model formulation. Given the stated intention of those GS contributions to provide tactical/strategic decision support such an approach is justifiable. Nevertheless, the lack of a clear operational description of the flexibility measure leaves the information and material flow representation somewhat incomplete and thus renders the entire approach controversial.

We incorporate operating flexibility in the form expediting into the GS model formulation. We allow for a restriction on the expediting probability, quantity and/or timespan. Through the incorporation of expediting we can work directly with the external demand as in the SS approach and the entire material flow is easy to trace and understand. We find that whereas the SS approach minimizes the on-hand stock (apart from the pipeline inventory), the GS approach, when entering the unbounded external demand, actually minimizes the safety stock enabled by the expediting option. The standard GS approach represents a special case of our new model where the expediting probability restriction is connected to the demand bound and the expediting timespan is equal to the coverage time of a stage. We also numerically explore the performance of our extended GS model.

Keywords: *safety stock; multi-echelon; guaranteed service; bounded demand; operating flexibility*

Planned Lead Times in Assemble-To-Order Systems

Ton de Kok

Eindhoven University of Technology, Eindhoven, The Netherlands

Order-driven assembly systems with throughput time uncertainty in each assembly stage can be controlled by so-called planned lead times. These planned lead times constitute planned start and end times for each assembly stage. In case an assembly stage finishes before its planned end time, the assembly stage reports being finished at the planned end time, otherwise it reports being finished at its actual finish time. A subsequent stage can only start when all preceding stages have reported that they have finished. Earlier research has revealed that for a two echelon assembly system the optimal planned lead times satisfy Newsvendor-type equations, determined by fractiles derived from the linear earliness costs at all stages and linear penalty costs at the final assembly stage. In this presentation we discuss the principles of the proof yielding these Newsvendor-type equations and possible further extension to more general order-driven assembly systems and systems with both demand uncertainty and lead time uncertainty.

Stochastic Optimization Methods in Inventory Control

Abel Cadenillas[1,2], **Peter Lakner**[3], Michael Pinedo[3]

[1] *Department of Mathematical and Statistical Sciences, University of Alberta, Edmonton, Canada*
[2] *Graduate School of Financial Engineering, Ajou University, Suwon, South Korea*
[3] *Department of Information, Operations and Management Sciences, Stern School of Business, New York, United States*

In this presentation a we shall review different continuous time optimization methods applied to various models for optimal inventory control problems. In one of these models the inventory level follows a mean-reverting process, and the manager is allowed to intervene in the form of major purchases or quick sales of goods. There are fixed and variable costs associated with each intervention, and also there is a cost for the inventory being away from the optimal level. This problem lends itself to the technique of impulse control, and we find the optimal solution. In another model we assume that the cumulative consumer demand for an item follows a Brownian motion, with both drift and variance parameters modulated by a continuous-time Markov chain that represents the state of the economy. The management of the company would like to maintain the inventory level as close as possible to a target level, and also would like to produce at a rate that is as close as possible to a target production rate. We consider two variations of this model. In the first case the management of the company knows exactly the state of the economy, whereas in the second they can only estimate it. We solve both problems by applying the technique of completing squares and obtain the optimal production policy and the minimal total expected discounted cost. We furthermore compare the total expected discounted costs of these two cases, and determine the value of information concerning the state of the economy. We also solve the above problems in the case when the consumer demand rate follows a geometric Brownian motion, modulated by the same continuous-time Markov chain that represents the state of the economy.

Keywords: *Inventory, production, demand, stochastic optimization, uncertainty.*

A Joint Replenishment Problem with Distance Dependent Joint Order Costs Using Additive Value Functions and Transport Cost Allocation Schemes

Christian Larsen

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

A set of retailers is served from a central warehouse where the total transport cost, for serving a subset of retailers together in one common shipment, is mainly proportional to the total distance travelled. The case where all the retailers are located along a major traffic artery, that is a one-dimensional line structure, is analyzed. Solving the problem by use of dynamic programming will suffer from the curse of dimensionality. Therefore we propose a decomposition scheme which is denoted adaptive cost allocation. The idea is that to each retailer there is estimated an approximate one-dimensional value function. In order to do so, there must to each retailer be developed an allocated order cost which is an approximation of the transport cost of serving the retailer. The value function and the allocated order cost are then updated along a sample path. Different cost allocation schemes are devised, among others by using Shapley values. We investigate numerically how different cost allocations methods compare to each other. We also compare the adaptive cost allocation method to other traditional approaches like using power-of two policies and zoning strategies. The investigations are conducted both in the case with or without capacity restrictions on the vehicles that do the transports.

***Keywords**: Joint replenishment, Transportation, Approximate dynamic programming, Cost allocation*

Development of a Failure-Prone Manufacturing System Control Policy with Inventory Inaccuracy and Stochastic Demand

Nan Li, Felix T. S. Chan, S. H. Chung

Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong

This paper discusses the optimal control policy of a manufacturing system constantly subjects to failures under the circumstance of inventory inaccuracy and stochastic demand. The traditional optimal control policy for failure-prone system usually assumes that the inventory level is accurate. However in reality, the inaccuracy in the whole supply chain is common and can't be ignored.

In this paper, a single machine, single product manufacturing system is used. The failures and repairs of machine are modeled by exponential distribution. Meanwhile, the demand is modeled as Poisson process with changing intensity parameters and unmet demand is backlogged. A mathematical model is then built considering both the uncertainty in demand and observed inventory level. The overall objective is to minimize the long term average holding cost and backlog cost. Along with the minimization, the optimal hedging point is determined.

Numerical experiments and simulations are then carried out to test the robustness of the proposed model. The results of this model are compared with the original hedging point policy against both the cases with inventory inaccuracy or without the inaccuracy. The differences between the trajectories in the two cases are used as an important measurement of the performance.

As the preliminary results suggest, the proposed model is more sensitive to the existence of inventory inaccuracy and provide more robustness than the original one. The overall cost in the proposed model is reduced by the value changing from 3.2% to 10.5% for observation error levels ranging from 1% to 5% respectively. Comparison between the proposed policy and the original one also indicates the significant influence of inventory inaccuracy on optimal hedging point in the manufacturing system.

Keyword: *inventory inaccuracy; stochastic demand; hedging point; failure; inventory management*

Stock Dependent Inventory Models under Parameter Uncertainty

Sungmook Lim

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

We consider a robust optimization model of determining an optimal order policy for items with an inventory level-dependent demand rate where demand rate is modeled as a decreasing power function of inventory level. While the general form of power function is given, it is assumed that parameters defining the power function involve a certain degree of uncertainty and their possible values can be characterized by ellipsoids. We show that the robust optimization problem can be transformed into an equivalent convex optimization which can be solved efficiently and effectively. In addition, we propose a practical (improved) implementation of the model, where the stochastic characteristics of parameters are obtained from regression analysis on past sales and production data, and ellipsoidal representations of the parameter uncertainties are obtained based on a combined use of genetic algorithm and Monte Carlo simulation.

An Inventory Model for a Dual Channel Retailer Selling Substitutable Products

Mohamed Ibrahim Mahaboob

McMaster University, Hamilton, Canada

In this paper, we develop an inventory model for a retailer who maintains two channels – a store channel and an online web channel and sells two products that are substitutes. Based on consumer behavior, the substitution is one-way or retailer (manufacturer) substitution on the online channel and two-way or stock-based consumer substitution in the store channel.

Synchronized Coordination in a Single-Vendor Multi-Buyer Supply Chain with Reverse Logistics

Nora Man, Chi Kin Chan, Y.C.E. Lee

Department of Applied Mathematics, The Hong Kong Polytechnic University, Hung Hom, Hong Kong

Objectives of study: This paper proposes a coordinated single-vendor multi-buyer supply chain model by synchronizing delivery, used item pick-up and production cycles. It is an extension of the model of Chan and Kingsman (2007) in which the supply chain now also includes reverse logistics and both the delivery cycles and used item pick-up cycles are integer factors of the production cycle.

Materials and methods: Three sets of data are used for numerical experiments. Example 1 with 5 buyers is from Banerjee and Burton (1994) with randomly generated recycling rates and costs added. Data for 30 and 50 buyers are randomly generated in Example 2 and 3, respectively. D/P is the ratio of the system demand per period to the vendor's production rate per period. As different values of D/P may have different effects on different models, we include a full range of different values of D/P from 0.1, 0.2, …, 0.9 for comparison. The synchronized cycle model with recycling production is solved by the genetic algorithm (GA).

Results: The results of the synchronized cycle model with recycling production are compared with the performance of buyers and vendor operating independently. The average percentage decrease in the total relevant costs is 35%, 33% and 31% in Example 1, 2 and 3 respectively. The division of the system costs between the vendor and buyers is also examined. On average, the buyers' costs in the synchronized cycle model have an increase of 56%, 33%, and 25% while the vendor's cost has a decrease of 67%, 65%, and 58% in Example 1, 2, and 3 respectively, when compared to the independent policy.

Conclusions: In all the examples, the buyers' costs for the independent policy are about one-third of the vendor's costs. The large saving for the vendor in the synchronized cycle model more than outweighs the increase in the buyers' costs so that there is still over 30% of saving for the system compared to the independent policy.

Keywords: *Supply chain coordination; Joint replenishment; Multi-buyer; Synchronized cycles; Reverse logistics.*

Designing Multi-Period Supply Contracts in a Two-Echelon Supply Chain with Asymmetric Information

Zahra Mobini, Wilco van den Heuvel, Albert Wagelmans

Econometric Institute and Erasmus Research Institute of Management,
Erasmus University Rotterdam, Rotterdam, The Netherlands

In a two-echelon supply chain consisting of a supplier and a retailer, we study how the supplier can use a specific incentive scheme - making a side payment - to influence the retailer's ordering plan. By using this simple and easily implementable scheme, the supplier reduces his production cost, thereby reducing the supply chain's total costs. The supplier makes a take-it-or-leave-it offer to the retailer, in the form of a menu of "procurement plan-side payment" contracts, and the retailer either accepts one of the contracts or imposes his individual optimal plan. We formulate the design of the supplier's optimal contracts with the assumption that the retailer possesses private information about customer demand and his cost parameters, and the supplier only knows the probability distribution of this private information. Taking into account the retailer's reaction to the proposed offer, the supplier faces a nested (bi-level) optimization problem, which we transform into a single-level mixed integer programming formulation. Our numerical study shows the potential of the proposed coordination scheme to improve the performance of the supplier, and as a result, the entire supply chain.

Keywords: *supply chain, coordination mechanisms, lot-sizing, asymmetric information, side-payment*

A Game Theoretic Analysis in Capacity-Constrained Supplier-Selection and Cooperation by Considering the Total Cost of Logistics

Davood Mohammaditabar[1], Seyed Hassan Ghodsypour[2]

[1] *Department of Industrial Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran*

[2] *Amirkabir University of Technology, Tehran, Iran*

The first models of supplier selection were based on maximizing buyer's interests. Recently, with the growing attention towards supply chain competition and vertical coordination, some researchers propose models that select suppliers based on total supply chain cost. These models, usually consider a centralized system to tackle the problem of proper incentives for members in cooperation. Our purpose in this paper is to analyze the selected suppliers and prices that are agreed on in decentralized supply chains. Also we aim to study the condition that the selected suppliers are in the benefit of the total supply chain. We use the inventory related costs to calculate payoff function of buyer and suppliers.

At the beginning of this paper, we develop the centralized model as a benchmark. Then we investigate the problem in a decentralized supply chain while suppliers have capacity constraints. We use cooperative and non-cooperative game theory to analyze the selected suppliers and total supply chain costs in two scenario. In the first scenario, suppliers act independently while in the second scenario suppliers cooperate and make coalitions. It is shown that, when suppliers have equal opportunity costs for each single production capacity, selected suppliers under the cooperative scenario are those that maximize the total supply chain cost. But when suppliers act independently or have different opportunity costs, the selected suppliers might not be those that make the optimal supply chain. A numerical example clarifies the findings.

Keywords: *supplier selection, decentralized supply chain optimization, buyer vendor coordination, game theory, inventory management*

Artificial Bee Colony for Inventory Routing Problem with Backordering

Noor Hasnah Moin, Huda Zuhrah Ab. Halim

Institute of Mathematical Sciences, University of Malaya, Kuala Lumpur, Malaysia

This paper addresses the inventory routing problem with backordering (IRPB) with a one-to-many distribution network, consisting of a single depot and multiple customers. IRPB considers vehicle routing and inventory holdings and backorder decisions for the specified planning horizon. A fleet of heterogeneous vehicles deliver multiple products to fulfill the customers demand over the planning horizon. We assume that the depot have sufficient supply of items that can cover all the customers' demands for all periods. The demand considered is relatively small compared to the vehicle capacity, and the customers are closely located such that a consolidated distribution strategy is appropriate. The backorder situation considered here is when the backorder decision either unavoidable (insufficient vehicle capacity due to the limited number of vehicles) or more economical (savings in the coordinated transportation cost are higher than the backorder cost). The objective of IRPB is to minimize the overall cost such that transportation cost, inventory cost and backorder cost is optimal. We proposed a metaheuristics method, Artificial Bee Colony (ABC) to solve the IRPB. The ABC algorithm is a swarm based heuristics which simulates the intelligent foraging behavior of a honey bee swarm. The intelligent behaviour referred to the act of honey bee searching the food sources (known as nectar) and sharing that information of the food sources with the bees in the nest. The bees are classified into three agents: the employed bee which carries the information about the food source (the distance, direction and the profitability), the onlookers bee watching the dance of the employed bees within the hive and making the decision to choose a food source based on the dances, and the scout bee is the bee performing random search for the food sources, around the nest environment. We modify the standard ABC algorithm by incorporating the inventory and backorder information. We propose a new inventory updating mechanism incorporating the forward and backward transfers. The modification also being made in the selection mechanism by the onlookers bee based on the waggle dance performed by the employed bees. We compare the results with the upper and lower bound found using CPLEX 12.6 and our algorithms perform better especially in large instances.

Keywords: *Inventory routing with backorder, Inventory management, artificial bee colony algorithm, metaheuristics,*
vehicle routing problem

Mathematical Models for Sizing Rental Products: A Case Study

Susumu Morito

Waseda University, Tokyo, Japan

A crucial decision of a rental business is the determination of the size of rental products available for customers' rental needs. We consider in this paper a specific company engaged in rental business. The company not only rents products, but also sells used products to customers normally when products get obsolete. The company also manufactures the products to rent. Rental demands fluctuate over time with some seasonality and trend. There exist several different product types but each product type can be considered as independent. Average rental period is roughly 6 months, and the number of products per customer ranges from 1 to exceptional cases of more than 100 with the average of 3.6.

The problem of interest is to determine the size of rental products (sometimes called capacity management), given rental demand forecast and used product sales forecast assuming a single product type. More specifically, the company wants to determine each month the amount of new products to be added to the rental system, which determines the size of rental products. The problem can be regarded as a one of specialized inventory control. Difficulty of the problem arises from random and systematic fluctuations of demands and also from the fact that monthly decision must be made when the average rental period is approximately half a year. We note that past studies on the problem of sizing rental products have been very limited despite its importance (see, e.g., Papier and Thonemann, Transportation Research, 2008).

Two alternative approaches have been considered and they augment each other. One is a simple mathematical programming model to determine monthly quantities for product addition, and the other is a simulation model based on the queuing model. In the mathematical programming model, monthly quantities for product addition are determined so that the "utilization" of products during the pre-determined planning horizon is as close to a target utilization level (say, 85%) as possible, where utilization is defined as the proportion of the products currently rented to customers to the total products owned by the company. Inputs to the model are forecasted demands and sales which are assumed to occur with certainty, the problem is formulated as a deterministic quadratic program with linear constraints, easily solved by optimization packages. Since the deterministic model does not consider randomness, discrete event simulation is performed to validate the results of the deterministic model.

Computational experiments based on real data show that the simple deterministic model yields results which are robust even under uncertain environment.

Keywords: *capacity management, rental products, revenue maximization, quadratic programming, discrete event simulation*

Joint Replenishment Problem with Dynamic Can-Order Policies under Carrier Capacity

Keisuke Nagasawa[1], Takashi Irohara[1], Yosuke Matoba[3], Shuling Liu[3]

[1] *Department of Information and Communication Sciences, Sophia University, Tokyo, Japan*

[2] *Fairway Solutions Inc., Tokyo, Japan*

Effective inventory management has played an important role in the success of supply chain management. Now, we consider a multi-item inventory. For managing multi-item inventory, generally we apply ordering policies for each item or coordinate replenishment of items for minimizing total cost. The latter problem is called Joint Replenishment Problem (JRP).

In our model, the target warehouse sells multiple items for retailer's demand and replenish items from a supplier. At each ordering, warehouse decides which item should be ordered and how much should be ordered. For the replenishing of the items, carriers with a finite capacity are available. The carriers dispatched from supplier arrive at the target warehouse after a fixed lead time. And, fixed ordering costs of each carrier is charged independent on the amount of orders but depend on the number of using carriers and the number of varieties of ordering items.

In this situation, because of the expensive stepwise ordering costs, using items group replenishments and full truckload replenishments may lead to substantial cost saving, even if the ordering item is not scheduled. Can-order policy is suitable for this situation. For the JRP, several researchers apply can-order policy. Under the can-order policy, some items are re-ordered when the inventory position drops to or below re-order level and any items with inventory position at or below its can-order level can be included in the order. Several researches consider how to set parameters of can-order policy

In this paper, we propose dynamic parameters setting method for can-order policy, can-order level, for each item at each ordering timing under carrier capacity. The main objective in our model is minimizing total cost consisting of items storages, stock-out and ordering cost.

In our numerical experiment, we consider capacity of carrier and simulate inventory movement and replenishing items. Experimental results of our proposed model are compared with the results of other methods. When the cost of each carrier is high, proposed method is effective. And sensitivity analysis is conducted to show the effect of key parameters affect the total cost. From the results of the sensitivity analysis, some interesting results are found.

Keywords: *inventory, joint replenishment problem, multi-item, can-order policy, carrier capacity*

The Consignment Stock of Inventories Under Buyer's Warehouse Space Limitation

Mohd Omar[1], Stanislaw Bylka[2]

[1] *University of Malaya, Kuala Lumpur, Malaysia*

[2] *Institute of Computer Science, Polish Academy of Sciences, Warsaw, Poland*

In this paper, coordination between a single vendor (or manufacturer) and a buyer (or retailer) via the delivery schedule in a production and distribution system is presented. A discrete deterministic model in which a vendor produces a product and supplies it to the buyer is considered. In the centralized decision process, the objective is to determine schedules which minimize the average total cost of production, shipment and stockholding. To satisfy the buyer's demands, the product is delivered in discrete batches from the vendor's stock to the buyer's stock subject to consignee's warehouse space capacity constraint.

Several authors incorporated policies in which sizes of successive shipments from the vendor to the buyer within a production cycle are equal in size.

We consider the following class of policies: The four decisions to take are the delivered amounts, the number of deliveries, and how many deliveries should be delayed for shipment. A (*k, n*)–policy requires:

Initial $k \geq 0$ sub-batches are identical in sizes (of the size q^v as the vendor preferred) precede $n \geq 0$ sub–batches also equal in sizes (q^b on the buyer mode).

Braglia and Zavanella (2003) and Zanoni and Grubbstrom (2004) consider the case $q^v = q^b$. The (*k, n*) - policies with $q^v \neq q^b$ can also be viewed from competition perspective - as non-cooperative individual strategies for production distribution system in Bylka (2011).

Modelling vendor - buyer relationships under (*k, n*)-policies

A vendor produces a product on a single machine and supplies it to the buyer. Buyer's demand is a continuous function of the time. We denote P = production rate of the vendor, D = demand rate of the buyer and

$I^v(t)$ = the vendor's inventory position at t just before the possible delivery;

$I^b(t)$ = the buyer's inventory position just before the possible replenishment;

$I^b(t^+)$ = the inventory position just past a replenishment at t, if any.

A schedule is determined by a sequence of cycles, each of them determined by a policy $\xi = ((q^v, k), (q^b, n))$, where $Q = kq^v + nq^b$ = the size of production batch, and (q_j, t_j) = quantity and the moment of j-th shipment, $j = 1, \ldots, m$.

For a feasible schedule on $[0, T]$, $T = \frac{Q}{D}$, we set

$$I^v(0) = 0, \quad I^b(0) = q_0 = \frac{q^v}{P}D \quad \text{and } \lambda = \frac{P}{D}$$

and we have

$$t_j = j\frac{q^v}{P} \quad \text{for} \quad j = 1, \ldots, k \quad \text{and} \quad I^b(t^+_{k+i}) = I^b_{max} \text{ for } i = 0, 1, \ldots n \quad \text{and}$$

$$(q_j, t_j) = \begin{cases} (q^v, j\frac{q^v}{P}) & \text{for} \quad j = 1, \ldots, k, \\ (q^b, k\frac{q^v}{P} + (j-k)\frac{q^b}{D}) & \text{for} \quad j = k+1, \ldots, k+n. \end{cases} \tag{1}$$

Each such a schedule determines the inventory position functions $I^v(t)$ and $I^b(t)$.

Particulary, for the replenishment moments we have:

$$I^b(t^+_j) = \begin{cases} jq^v - \frac{(j-1)q^v}{\lambda} & \text{for} \quad j = 1, \ldots, k, \\ I^b(t^+_k) = I^b_{max} & \text{for} \quad j > k. \end{cases} \quad \text{and} \quad I^b_{max} = q^v\frac{1 + k(\lambda - 1)}{\lambda}. \tag{2}$$

As usually, the main problem consists in the allocation of total stored quantity in vendor's and buyer' stocks. In the model above, it is determined by a CS (*k, n*)–policy. The important quantity connected with CS-policies is the maximal buyer's inventory position. By Eqs(1)–(2), it is easy to see that I^b_{max} dependsÍrja be az egyenletet ide on all decision variables. The idea of CS-policies states that I^b_{max} can be given (with the agreement or by the technological possibilities) as a parameter of the model. We present a solution in the case under buyer's space limitation I^b_{max} as a given constraint. We use the Goyal's numerical example to present our solution procedure for CS (*k, n*) policies. The total cost found by the method in this study can be compared with the costs found in two papers, where the same numerical example was tested.

A Production-Repair Inventory Model with Time-Varying Demand and Multiple Setups

Mohd Omar[1], Ivan Yeo[2]

[1] *Institute of Mathematical Sciences, University of Malaya, Kuala Lumpur, Malaysia*

[2] *Department of Mathematical and Statistical Sciences, UTAR, Jalan Genting Klang, Kuala Lumpur, Malaysia*

In this paper, we proposed a model for a inventory system that satisfies a continuous time-varying demand for a finished product over a known and finite planning horizon by supplying both new and repaired items. New items are fabricated from a single type of raw material procured from external suppliers, while used items are collected from the customers and then repaired to a condition that is „as good as new". During each time interval, new items and used items are produced from multiple production and repair runs. The problem is to determine a joint policy for raw materials procurement, new items fabrication, and used items repair such that the total relevant cost of the model is minimized. We also proposed a numerical solution procedure and we tested the model with some numerical examples and a simple sensitivity analysis.

Keywords: *inventory; production; time-varying demand; reuse*

An EOQ Model with Stochastic Supply Disruptions

Konstantina Skouri[1], Ioannis Konstantaras[2], Atanassios G. Lagodimos[3]

[1] *University of Ioannina, Department of Mathematics, Ioannina, Greece*
[2] *University of Macedonia, Department of Business Administration, Business Excellence Laboratory, Thessaloniki, Greece*
[3] *University of Piraeus, Department of Business Administration, Piraeus, Greece*

We consider an inventory system facing deterministic demand in order to study the effects of imperfect supply on cost performance. As, the supply process is imperfect, there is a finite probability of defective delivery batch (i.e. bellow quality standards). Also, we assume that defective delivery occurrences are independent of each other. To control the process, an "all or none" policy is assumed. So, all batches are inspected and, if found defective, they are rejected (the respective delivery batch quantity does not enter inventory). Such failures represent the supplier's inability either to physically deliver or to meet agreed quality standards. There are no emergency deliveries, so the quantity of any defective batch is routinely added to the quantity of next delivery. The purpose of this study is to model system cost per unit time and to determine the optimal values of the decision variables (i.e. order-up-to level and review interval). Analytical and computational results reveal the serious impact of inferior supply on system cost.

Keywords: *supply chain; supply disruptions; uncertainty; newsvendor; shortages*

Optimal Timing for a Newsvendor Problem with In-Season Price Adjustment

Piotr Staliński[1], Chia-Shin Chung[2]

[1] *Wyższa Szkoła Biznesu, National Louis University, Nowy Sącz, Poland*
[2] *Cleveland State University, Ohio, USA*

We investigate a single period inventory-pricing problem for a seasonal product. The demand is uncertain and multiplicative with constant price elasticity. We assume there exists a single opportunity to adjust the price during the season, as demand is observed. The key decision variables are the optimal timing and the optimal pricing of the in-season price-adjustment. The objective is to maximize the expected profits. We establish important properties of the optimization problem and propose an efficient procedure for finding the optimal timing of the price adjustment. We report the results of the numerical experiments that indicate how demand variability and price elasticity affect both the optimal solution and the value of the flexibility to adjust the price.

Refund Policies for Core Collecting from the Customers' Perspective

Shuoguo Wei, Ou Tang

Division of Production Economics, Department of Management and Engineering, Linköping University, Linköping, Sweden

Cores are essential resources for the remanufacturing business. The lack of cores with proper quality is one serious barrier for the profitability of both independent and OEM (Original Equipment Manufacturer) remanufacturers. To encourage the return of quality cores, in practice it is common for OEMs (for example, Caterpillar Reman) to charge a certain amount of deposit during customer's purchasing, and refund it fully or partially depending on the quality of cores in the later return process. The refund policy thus plays an important role on influencing the quantity and the quality of the returns.

On the other hand, the customers' responses to the refund policies could be very complicated. The customers could choose to return the cores to the OEM to receive the refund, or alternatively they can sell it to other core collectors who offer more appealing prices; if the refund policies are properly set and explained, the customers may be motivated to carefully maintain the quality of the cores, or they could refuse purchasing the products from the beginning due to the fear of not receiving deposit later. Such responses are affected by various factors such as, the competition level of the core collecting market, the customers' personal preferences and their information about the quality of the cores, etc. Understanding the customers' possible responses and designing proper refund policies accordingly are critical for the success of the core collecting process and therefore the remanufacturing operations.

In this paper, we firstly build up a decision model to describe clearly the customers' payoff and possible responses with respect to the refund policies. Secondly we try to include the remanufacturer's decisions process within a game theory framework, in order to decide proper refund policies that suit specific remanufacturing environments.

Keywords: *remanufacturing, refund policies, core quality, decision process, game theory*

Analytical Insights into the Two-Stage Serial Line Supply Chain Configuration Problem

Sean P. Willems[1], N. Grace Hua[2]

[1] *School of Management, Boston University, Boston, United States*

[2] *Cisco Systems, Inc., San Jose, United States*

Design-and-development buyers sourcing new supply chains and strategic sourcing analysts making outsourcing decisions for existing supply chains are in different organizations but share a common problem. Both determine whether an existing part should be replaced. Relative to the existing part, new candidates could be cheaper, yet longer leadtime, or more expensive and shorter leadtime. Furthermore, a longer leadtime part could be buffered with inventory and this could be cheaper than paying more for a shorter leadtime part.

To derive analytical insights into the nature of this problem, we develop a two-stage supply chain configuration model to jointly determine the chosen part and inventory stocking level at each stage to minimize cost of goods sold, pipeline stock cost and safety stock cost.

We prove it is preferable to synchronize the supply chain by employing the same type of option, be it low cost long leadtime or high cost short leadtime, at both stages.

We prove that the selection threshold for high cost short lead time options is lowest at just the downstream stage, highest for just the upstream stage, and between these extremes if such a candidate is selected for both stages. If a part's cost-time relationship follows a functional form, we establish conditions when it is optimal to choose the lowest cost, longest leadtime, option available.

Keywords: *supply chain sourcing; supply chain design; multiechelon inventory system; supply chain configuration; guaranteed service model of safety stock optimization*

The Effect of Payment Schemes on Supply Chain Performance in E-Business

Na Xu, Shizen Bai

School of Management, Harbin University of Commerce, Harbin, China

With the tremendous growth in electronic commerce in recent years, many online retailers are trying different ways to improve customer satisfaction.

As the key process in e-business, payment scheme has attracted great attention by industries. Nowadays, the most frequently used is prepayment through internet, which is convenience and efficiency. What's more, it seems to reduce the perceived cost of the product, which is helpful to increase sales. Yet, some researches indicated the purchase and payment decisions of customers may be suppressed by the valuation uncertainty in e-business, stimulating more kinds of payment ways to attract customers, like payment after delivery.

This payment scheme can efficiently eliminate the uncertainty because the payment is made for the delivered product while extra costs occur for both retailers and consumers. Therefore, it is significant to clarify the relationship between payment schemes and e-business operations. However, this aspect is almost blank in the academic field. Our paper tries to make optimal operating decisions with different payment schemes to improve profit, as well as provide precise guidelines for online retailers, by analyzing the inherent relationship between payment schemes and supply chain performance.

Since customers do actively evaluate alternatives and make choice, we consider an online retailer facing with loss aversion consumers, which is different from previous studies that are based upon normative models of customer behavior. Combined with prospect theory, we build the utility function model of consumers under the two payment schemes mentioned above. Then, try to find rational expectations (RE) equilibrium of the model to get the optimal operating decisions for online retailers under each payment scheme.

Furthermore, we extend the concept to the case of decentralized supply chains with a single online retailer and a single manufacture. Considering the influence of service level and product quality on the RE equilibrium, some contracts come forward to ensure supply chain performance.

This research could help online retailers find the optimal operating decisions with different payment strategies, also improve the efficiency of the supply chain in e-business. Furthermore, our research combines customer behavior and operating decisions from the perspective of payment, which provides some support to the academic richness and practical applicability of operations management in e-business.

A Joint Economic Lot Size Model with Contract Manufacturing

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

Department of Mechanical and Industrial Engineering, Università degli Studi di Brescia, Brescia, Italy

This contribution presents a production-inventory model for a supply chain consisting of a supplier (S), a manufacturer (M) and a contract manufacturer (CM). The manufacturer purchases raw materials from a supplier and performs preliminary manufacturing operations; afterwards, the semi-finished goods are sent to the contract manufacturer for additional manufacturing operations and, finally, the finished goods are sent back to the manufacturer ready to be sold to the buyer.

The aim of this work is to analyze two different supply chain configurations involving outsourced manufacturing operations with the contract manufacturer: the first option is to consider a traditional production-inventory arrangement; the second one involves a consignment stock agreement between the manufacturer and the contract manufacturer of the finished goods. Considering the traditional supply chain configuration, the contract manufacturer will ships to the manufacturer equally sized batches, only when the previous batch at the manufacturer warehouse has been completely depleted by the buyer demand.

Alternatively and under the consignment stock agreement, the contract manufacturer will ship to the manufacturer equally sized batches immediately when finished. Additionally, the contract manufacturer under the consignment stock agreement will receive payments for the goods transferred only when they will be depleted at the manufacturer warehouse by the customer demand.

These two structures present different material, information and cash flows. The main difference between the two considered structures lies in the structure of the inventory holding costs. Within the traditional supply chain configuration, the manufacturer is responsible for the financial component of the holding cost of the goods stored by the contract manufacturer, considering both purchasing and transformation value. Under the consignment stock agreement, the manufacturer is responsible only for the purchasing value part of the financial component of the holding cost of goods stored by the contract manufacturer supplier, while the contract manufacturer is responsible for the transformation value component of the financial holding cost.

Finished goods are assumed to have price-independent deterministic demand, while cost components are assumed to be constant over time. The analysis is carried out considering as main performance indicator the system annuity stream.

The main interest in this research is to understand how different managerial configurations of the supply chain inventory affect the system performance, such as the annuity stream, considering the contract of work with sub-tier supplier under different agreement structures, i.e. traditional or consignment stock oriented.

Keywords: *Jels, supply chain, outsourcing, consignment, contract manufacturing*

Modelling Supply Chains by Hydraulics

Simone Zanoni[1], Lucio Zavanella[1], Mohamad Jaber[2]

[1] *Universita di Brescia, Brescia, Italy*
[2] *Ryerson University, Toronto, Canada*

Supply Chains may be essentially regarded as a flow of items/commodities from an upstream producer toward a final market: the flow is conveyed by transport means and intermediate storages may be provided to guarantee service supply, included operations on the items. These steps resemble to fluid flows from an original reservoir to their final utilization (fluids move into pipes and are accumulated into intermediate tanks/reservoirs). According to the similarities briefly outlined, the objective of the work is to show how the relationships between hydraulics and Supply Chains are able to offer original insights and views on the dynamics of the Supply Chains. To this end, the work pays attention to the possibility of explaining the "links" between the two systems (hydraulics and Supply Chains), thus considering the opportunities for exporting hydraulic laws and methods to the Supply Chain modeling and, consequently, design.

As far as the adopted methods are concerned, a preliminary review will sum up those contributions which already paid attention to the usefulness and applicability of "hydraulic models" to Supply Chain understanding. Consequently, a conceptual scheme (allowing the understanding of the parallelism between the two systems) will be detailed, thus introducing the potential applications of equations from hydraulics laws to Supply Chain modeling. Therefore, the method of the study is mainly conceptual, even if its final aim is to propose a framework for practical applications. In fact, according to the interpretation given, the utilization of laws and tools from hydraulics will be described as a promising method in the design of Supply Chains. Simple examples will allow the understanding of the conceptual relationships proposed: in the authors' perspective, the results obtained will also support and/or give managerial insights.

In conclusion, the study is an exploratory one, mainly based on an original approach to Supply Chain design, offering a view on wider applications and improvements.

Dynamic Lot Sizing for Products with High Setup Cost Subject to Obsolescence

Luca Zeppetella, Elisa Gebennini, Andrea Grassi, Bianca Rimini

Dipartimento di Scienze e Metodi dell'Ingegneria, Universitá degli Studi di Modena e Reggio Emilia, Reggio Emilia, Italy

In several industries, sudden changes in technology, fashion and style make the product useless for its intended use at some point in time and hence its utility and therefore its demand drops to zero at that point. The increase of set-up costs and the fragmentation of order quantities that have taken place in recent years make the lot-for-lot policy unsuitable in make-to-order environments. Thus, firms have to face the obsolescence risk and to produce, at their own risk, more than the ordered quantities. In this study, we propose a dynamic lot size model for an inventory management problem emerged in a real-world case study in the plastic injection molding industry and common to many other contexts. In particular, products are supposed to have a stochastic life cycle highly influenced by engineering changes or fashion updates.

In order to optimize the production planning activities, an analytical model was developed to identify the optimal production lot size considering the risk of obsolescence faced by the firm. The model assumes time-fixed periods and a single product with deterministic time-varying demand. Among a long-term demand forecast only the demand of the first next period has certain occurrence. Demand, demand forecast and product life cycle distribution are subject to possible revisions in every period. The risk of obsolescence is related to the product life cycle distribution assumed a priori and the risk is computed as a penalty on the holding cost.

The study highlights that the optimal lot size depends on the position of the product in the life cycle distribution. In each period, the revision of model parameters is allowed and the optimal production plan is consequently re-evaluated. Such a flexibility increases the applicability of the model in practical real-life contexts.

The validity of the model is proved by discussing a real case study and providing a differential analysis between the actual lot sizing strategy and the model results.

Given a long-term forecast and a deterministic but uncertain time-varying demand, the proposed model provides the production lot sizes according to the obsolescence risk due to engineering changes or fashion updates. The model has its strength in the adaptability to the updating process and the possibility of adjusting existing production plans through successive runs of the model. We compared the performance of different product life cycle profiles and showed the advantages of our model over the traditional lot sizing techniques in the scenario proposed.

Keywords: *inventory, lot sizing, obsolescence, product life cycle, risk*

Forecasting for Inventories

A Forecasting Strategy for Supply Chains Where Information Is Not Shared

M.M. Ali[1], **Mohamed Zied Babai**[2,3], JohnE. Boylan[3], Aris A. Syntetos[4]

[1] *Coventry University, Coventry, United Kingdom*
[2] *Kedge Business School, Talence, France*
[3] *Bucks New University, Buckinghamshire United Kingdom*
[4] *Cardiff University, Cardiff, United Kingdom*

The operations management literature is abundant on discussions on the benefits of information sharing in the supply chains. However, there are many supply chains where information may not be shared due to constraints such as compatibility of information systems, information quality, trust and confidentiality. Furthermore, a steady stream of papers has explored a phenomenon known as Downstream Demand Inference (DDI) where the upstream member in a supply chain can infer the downstream demand without the need of a formal information sharing mechanism. Recent research has shown that under realistic circumstances DDI is not possible with optimal forecasting methods or Single Exponential Smoothing but is possible when supply chains use a Simple Moving Average (SMA) method. In this paper, we propose a simple DDI strategy based on SMA for supply chains where information cannot be shared. This strategy allows the upstream member in the supply chain to infer the consumer demand mathematically rather than sharing this. We compare the DDI strategy with the existing No Information Sharing (NIS) strategy and an optimal Forecast Information Sharing (FIS) strategy in the supply chain. The comparison is first made analytically followed by experimentation on real sales data from a major European supermarket located in Germany. We show that using the DDI strategy reduces the Mean Square Error (MSE) and inventory costs in the supply chain.

Keywords: *information sharing, forecasting, simple moving averages, ARIMA methodology, downstream demand inference*

Implications of Forecast Combination for Inventory Management

Devon Barrow, Nikolaos Kourentzes

Lancaster Centre for Forecasting, Department of Management Science, Lancaster University, United Kingdom

Managingan effective inventory control system in the face of uncertain demand ischallenging. Strategies for dealing with this uncertainty rely on estimating accurately the demand. Accurate forecasts suggest less uncertainty about the future demand, which in turn results in needing less safety stock, with substantial implications for the financial health of companies. Forecast combinations have long been viewed as an effectiveway of reducing forecast error, as far back as the seminal paper by Bates and Granger [1]. They have also been found to improve the robustness of the resulting forecast, itself being less sensitive to potential limitations of a single model, or its poor fit to the historical demand. In general, the combined forecast is less reactive and hence more resistant to the inherent demand variability. This is a useful property for inventory management, as the forecasts and their errors, are more consistent over the different planning cycles, thus simplifying planning and ordering of stock. However, the research in forecast combination have focused rather specifically on improving forecasting accuracy and evaluating performance using only accuracy metrics, while largely ignoring the quality of the combined forecasts and the properties of the forecast errors [2].For example, the distribution of the combined forecast error will elicit different management responses depending on its shape and management's level of aversion to the risk and uncertainty reflected therein. With forecast combinations there is the potential departure of the forecast error distribution from the widely assumed normal distribution, which is critical to inventory management models and safety stock calculations. Surprisingly, the value to inventory management and the impact on inventory performance from combining different forecasts has been mostly ignored. In this studywe consider the impact of forecast combinations and the resulting errors, extending our analysis beyond forecasting accuracy to consider the impact on inventory metrics, such as realised service levels and out -of-stocks against stock holding. The study utilises a set of well established forecast combination rules and forecasting methods, and a set of real as well assimulated time series in order the measure the impact of forecast combinations.The evidence gathered indicates that forecast combinations appear to perform better than individual forecasts both in terms of accuracy and inventory performance.

***Keywords**: forecasting, combinations, inventory management, error specification*

References:

1. Bates, J.M. and C.W.J. Granger, The Combination of Forecasts.Operational Research Quarterly, 1969. 20(4): p. 451-&.

2. de Menezes, L.M., D.W. Bunn, and J.W. Taylor, Review of guidelines for the use of combined forecasts. European Journal of Operational Research, 2000. 120(1): p. 190-204.

On the Performance of Overlapping and Non-Overlapping Temporal Demand Aggregation Approaches

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

[1] *Buckinghamshire New University, Buckinghamshire, United Kingdom*

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

Demand uncertainty is among the most important challenges facing modern companies. The existence of high variability in demand for fast moving and intermittent moving items pose considerable difficulties in terms of forecasting and stock control. There are many approaches that may be used to reduce demand uncertainty and thus to improve the forecasting and inventory control performance. An intuitively appealing approach that is known to be effective is temporal demand aggregation, which refers to the process by which a low frequency time series (e.g. quarterly) is derived from a high frequency time series (e.g. monthly). There are two different types of temporal aggregation: non-overlapping and overlapping. In the former case, the time series are divided into consecutive non-overlapping buckets of time where the length of the time bucket equals the aggregation level. The latter case is similar to a moving window technique where the window's size equals to the aggregation level. At each period, the window is moved one step ahead, so the oldest observation is dropped and the newest is included. In this work, we analytically compare the performance of both approaches. By means of theoretical and empirical demand data, we show that, overall, the overlapping approach outperforms the non-overlapping one, especially for longer demand histories. We also show that the degree of outperformance of the overlapping approach increases as the degree of demand intermittence increases. However, for short demand histories, we show that the non-overlapping aggregation approach may outperform the overlapping one.

Keywords: *temporal aggregation, overlapping, non-overlapping, theoretical analysis, empirical investigation*

Forecasting of Business Data by Walsh-Transform Methodology

Erik Bajalinov[1], **Imre Dobos**[2], Szabolcs Duleba[1]

[1] *College of Nyíregyháza, Nyíregyháza, Hungary*
[2] *Corvinus University of Budapest, Budapest, Hungary*

In this paper we will present the Walsh transforms and its connection to time series analysis. The paper surveys the existing statistical literature to make effective approximation with dyadic harmonic analysis. We will point out that this mathematical discipline i.e. dyadic analysis makes it possible to fulfill fast calculation in approximation process. The approach is based upon literature reviews. The most important economic and business application of dyadic analysis is summarized. The summary enables to focus the analysis on new fields of time series analysis. Based on the existing research findings, it can be stated that dyadic harmonic analysis and Walsh-transforms may be highly effective techniques when we have to approximate functions and/or to construct forecasting for a time series.

This investigation is supported by TÁMOP-4.2.2.A-11/1/KONV-2012-0051 research program

***Keywords**: walsh-transform, time-series analysis, dyadic analysis, approximation*

Joint Optimisation for Essential Reduction of Supply Chain Costs

Liljana Ferbar Tratar

Faculty of Economics, University of Ljubljana, Ljubljana, Slovenia

Demand forecasting is used frequently in the world because of expedient source management and because the need for planning is becoming more important. Different methods of forecasting can be used, although exponential smoothing methods are most often used in practice because they are simple, fast and inexpensive. With regard to Pegels' classification of the usage of proper forecasting methods, Holt-Winters (HW) methods are appropriate for demand with additive trend and additive/multiplicative seasonality, but they are not accurate enough for demand with multiplicative trend and the large noise that is often a property of real data.

In this paper we present an improved HW method for demand with multiplicative trend and we show that the optimisation of the forecasting method should not be treated separately from the production or inventory model in which forecasts are used.

Inventory related decisions are crucial for increasing efficiency and improving customer service level. Demand forecasting and stock control are equally contributing towards such a decision making process. However, the stock control system is often examined independently of the demand forecasting process and as such the interactions between them are largely ignored. Regarding the process of forecasting demand, the main approach towards the selection and optimisation of alternative methods relates to the minimisation of forecast error measures such as the mean square error. However, such an approach does not consider explicitly the minimisation of the resulting costs.

The case of a centralised supply chain with an order-up-to inventory policy shows that calculated forecasts of demand, determined by minimising mean square error, are not optimal. We describe a method for simultaneous optimisation of the improved HW method and a stock control policy, where smoothing (and initial) parameters of the forecasting methods are determined to minimise the total costs. From the results obtained with simulated demand patterns and results for real data we show that essential reduction of supply chain costs can be achieved if we use the improved HW method for joined optimisation.

***Keywords**: demand forecasting, nonlinear time series, holt-winters method, inventory control, optimisation*

Inventory Implications of Forecasting with Temporal Hierarchies

Nikolaos Kourentzes, Fotios Petropoulos

Lancaster Centre for Forecasting, Department of Management Science, Lancaster University, United Kingdom

Forecasting future demand is essential for inventory management. Identifying the most appropriate time series model to achieve good forecasting accuracy is a challenging task. Particularly for demand planning applications, where one has to forecast a large number of items, it is important to be able to automatically and confidently select models and their parameters to produce the relevant forecasts. However, how to best select and parameterise models is still an open question.

Recently, the Multiple Aggregation Prediction Algorithm (MAPA) was introduced to mitigate the importance of model selection, while increasing forecasting performance [1]. The algorithm operates by transforming the original series to alternative frequencies, to construct new time series by means of non-overlapping temporal aggregation. These new time series strengthen and attenuate signals present in the original series. For example, seasonality is better captured at low temporal aggregation, while long term trends in the series are better captured at high aggregation levels. Appropriate univariate forecasting models are fitted to each time series and these are then combined into a single forecast that takes into account the information captured from the various temporal views of the data. MAPA results in better estimation of the different time series components, due to the temporal aggregation, and the importance of selecting each individual model correctly is mitigated, due to the combination of the various fitted models. Empirically it was shown to achieve significant improvements in forecasting accuracy, especially for long-term forecasts.

Although the MAPA is capable of producing accurate baseline forecasts, it does not cater for external drivers, such as promotions [2, 3] and point-of-sale data [4], which have been shown to be beneficial in the supply chain context. In this work we extend the formulation of MAPA to the multivariate case to include such information. With the proposed multivariate MAPA the impacts of the external drivers at the various levels of the temporal hierarchy are explored and new insights about their effect on inventory are gained. We demonstrate the benefits of the proposed multivariate MAPA using a real dataset from a case study company, against established univariate and multivariate benchmarks, as well as the original MAPA. The evaluation is done both in terms of forecasting accuracy and inventory performance.

Keywords: *forecasting, temporal aggregation, temporal hierarchies, MAPA, inventory management*

References

[1] Kourentzes, N., Petropoulos, F., & Trapero, J. R. (2014). Improving forecasting by estimating time series structural components across multiple frequencies. International Journal of Forecasting, 30(2), 291-302.

[2] Trapero, J. R., Pedregal, D. J., Fildes, R., & Kourentzes, N. (2013). Analysis of judgmental adjustments in the presence of promotions. International Journal of Forecasting, 29(2), 234-243.

[3] Trapero, J. R., Kourentzes, N., & Fildes, R. (2014). On the identification of sales forecasting models in the presence of promotions. Journal of the Operational Research Society.

[4] Trapero, J. R., Kourentzes, N., & Fildes, R. (2012). Impact of information exchange on supplier forecasting performance. Omega, 40(6), 738-747.

Extrapolation Demand Data Based on Walsh-Fourier Analysis

Balázs Lénárt, Krisztián Bóna

Budapest University of Technology and Economics, Department of Material Handling and Logistics Systems, Budapest, Hungary

Objectives of study: The analysis of time series in time domain is a widely investigated topic in logistics research, but the analysis in frequency domainless popular. However the capability in terms of decompression the time series into a superposition of different frequencies or sequences Fourier analysis can be used effectively for seasonal sales or demand forecasting. In this paper we present a discrete version of Fourier transformation - the so called Walsh - Fourier analysis - which is a fast and efficient method to analyze time series in frequency (sequence) domain. In our current research two forecasting methods are being developed based on Walsh-Fourier analysis. The first method is based on period and trend detection (Walsh-Period-Detection), the second is based on linear regression of the coefficient vector (Walsh-Linear).

Materials and *Methods:* In the classical Fourier analys is the spectral representation theorem says that we may think of a stationary time series as being formed by the random superposition of sine and cosine waveforms. The same basic ideas are employed in Walsh-Fourier analysis; however, these functions are square waveforms that take on only two values, + 1 and -1.

Results: Two time series is being investigated: an ideal sinusoidal series and the same dataset with some random noise. In case to compare the newly developed algorithms to traditional forecasting methods pre-identified ARIMA and SARIMA models were being used. The fitting of Fourier based solution (Walsh-Linear) is perfect which is caused by the linear trend and the periodicity of the original time series. The statistical results are being presented in Table 1

Table 1: *Statistical results of "ideal" time series*

	MAE	MdAE	MSE	RMSE
Walsh-Period-Detection	854	780	897 387	947
Walsh-Linear	0	0	0	0
ARIMA(2,1,2)	1 729	2 258	3 822 489	1 955
SARIMA(2,1,2)(1,1,1)	838	968	946 861	973

On the noisy dataset traditional Box-Jenkins models perform worse than the experimental Walsh-Fourier based extrapolation (see Table 2).

Table 2: *Statistical results of "noisy" time series*

	MAE	MdAE	MSE	RMSE
Walsh-Period-Detection	2 690	2 602	8 932 942	2 989
Walsh-Linear	6 795	5 417	71 613 792	8 462
ARIMA(2,1,2)	4 854	3 026	41 066 934	6 408
SARIMA(2,1,2)(1,1,1)	9 354	9 202	128 549 287	11 338

Conclusions: In this proposal fourstate-of-the-art forecasting techniques were compared.It was shown that the presented Walsh-Fourier based methods offer new opportunities in time series forecasting. For better results we proposeuse data cleansing techniques.

Keywords: *demand planning, forecast, Walsh-Fourier analysis, extrapolation*

Demand Forecasting in Supply Chains: A Comparison of State Space Models

John E. Boylan, **Mona Mohammadipour**

School of Business and Management, Buckinghamshire New University, High Wycombe, United Kingdom

This study compares multiple source of error (MSOE) and single source of error (SSOE) state space models in forecasting demand trends. The adoption of these models leads to parameter spaces that are constrained and differ from the traditional limitations of smoothing parameters between zero and one. The performance of applying constrained versions of Holt's method and the Damped Trend method, based on the two demand models, is tested using different forecasting accuracy measures.

Constrained methods are also compared to unconstrained versions using simulation and on empirical data. It is shown that improvements in forecasting accuracy can be obtained by constraining the smoothing parameters for these forecasting methods. The relationship between parameter spaces and accuracy is investigated both in terms of forecasting and inventory implications.

Keywords: *trend forecasting, state space models, holt's method, damped trend method*

Another Look at Estimators for Intermittent Demand

Fotios Petropoulos[1], Nikolaos Kourentzes[1], Konstantinos Nikolopoulos[2]

[1] *Lancaster Centre for Forecasting, Department of Management Science, Lancaster University, Lancaster, United Kingdom*

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

Forecasting for irregular demand is challenging. Intermittent demand is characterized by variable demand sizes coupled with irregular demand arrivals, with many observations having zero demand. Such demand patterns are very common in many industrial settings.

Croston (1972) proposed the decomposition of such data into two separate series, corresponding to the non-zero demand sizes and the inter-demand intervals. Each series is to be extrapolated separately, while the derived point forecasts are divided to create a forecast of the demand rate. The method models independently each type of variance observed in the data: the variance of the non-zero demands and that of the inter-demand intervals. Another way to look at this is that it is a non-overlapping temporal aggregation, using time buckets which length varies over time, so that: (i) exactly one non-zero demand is included in each bucket and (ii) intermittence is removed. However, as the length of the time buckets is time-varying, one has to forecast both demands and intervals.

Nikolopoulos et al. (2011) proposed the Aggregate-Disaggregate Intermittent Demand Approach (ADIDA), which uses equally sized time buckets to perform non-overlapping temporal aggregation. ADIDA reduces the variance observed in the intervals. Thus, given an appropriate level of aggregation, which removes the intermittence of the data, ADIDA focuses only on forecasting the (aggregated) non-zero demands. So, one could argue that the improvements in performances by the ADIDA framework derive from the reduction (or elimination) of the variance observed in the intervals.

However, instead of focusing on minimizing the variance of the inter-demand intervals and modeling the variance of the demand, one could fix the "demand buckets", thus minimizing the variance of the demand, and forecast the respective time-varying number of periods that this fixed demand will occur. In other words, answering the question: "how many periods will pass before a stock-out?" or, given a safety stock, "when should I re-order?". We call this new approach *Inverse ADIDA*. The proposed approach makes sense from a managerial viewpoint, as many SKUs are distributed in pallets with pre-fixed quantities.

This study introduces the Inverse ADIDA and empirically examines its performance against standard intermittent demand estimators and the ADIDA. Evaluation is performed both in terms of error metrics and inventory performance, using multiple data.

Keywords: *intermittent demand; forecasting; croston's method; ADIDA; aggregation; inventory performance*

References:

Croston, J. D. (1972). Forecasting and stock control for intermittent demands. Operational Research Quarterly, 23, 289-303.

Nikolopoulos, K., Syntetos, A., Boylan, J., Petropoulos, F., & Assimakopoulos, V. (2011). ADIDA: An aggregate/disaggregate approach for intermittent demand forecasting. Journal of the Operational Research Society, 62, 544-554.

Unconstraining Demand in the Car Rental Industry

Dong Li[1], **Arne K. Strauss**[2], Cuong Tran[3]

[1] *York Management School, University of York, York, United Kingdom*
[2] *Warwick Business School, University of Warwick, Warwick, United Kingdom*
[3] *Avis Budget Group EMEA (Europe, Middle East, Africa), Bracknell, United Kingdom*

Objectives of study: The product that a car rental company offers is the provision of a car at a specific station, date, length-of-rental, customer segment and rate. The products are perishable and can be booked in advance. In order to maximize revenues, car rental companies dynamically impose or lift restrictions on the availability of products in response to expected future demand. These decisions are mostly automated and are proposed by a revenue management (RM) system which takes expected demand as an input. However, forecasting demand is difficult because the company cannot observe sales that would have occurred during time periods when the product was unavailable, either because of restrictions or because of an anticipated stock out of inventory at the pick-up day. Hence we need to unconstrain the historic sales data so as to obtain a better estimate of true demand, which subsequently can be passed on to the RM system. The objective of this study is

- to develop an unconstraining method suitable to the challenges of the car rental industry,
- to test its accuracy on actual car rental data from our collaboration partner Avis Budget Group,
- to report on the impact of its implementation at Avis Budget Group.

Materials and Methods: The RM system requires unconstrained demand estimates at the product level. Historic booking curves for individual products are sparse (often less than 10 requests) and intermittent. The inter-arrival time of requests tends to become much shorter close to the pickup day. We propose to use a modified variant of Croston's method to unconstrain the data. It is based on a recently prosed unconstraining approach for the hotel sector (Queenan et al., Production & Operations Management1662007, pp. 729-746), but had to be modified since it needs to deal with much smaller samples.

Results: The method has been tested on real booking data and was implemented atAvis Budget Group EMEA; it is now integrated into their systems and is used in the daily operations. Various practical challenges arose that required us to modify the method accordingly. We also will present results on the accuracy of the method.

Conclusions: There exists a substantial body of literature on the topic of forecasting intermittent demand, as well as on unconst raining demand. However, little attention has been given to the intersection of these two areas. Our study is applied work with industry impact that addresses this gap.

Keywords: *unconstrained demand; intermittent demand; truncated demand; Croston's method; revenue management*

On the Calculation of Safety Stocks

Aris A. Syntetos[1], Ruud H. Teunter[2]

[1] *Logistics & Operations Management, Cardiff University, Cardiff, United Kingdom*
[2] *Department of Operations, University of Groningen, Groningen, The Netherlands*

In forecasting and inventory control textbooks and software applications, the variance of the cumulative lead-time forecast error is, almost invariably, taken as the sum of the error variances of the individual forecast intervals. For stationary demand and a constant lead time, this implies multiplying the single period variance (or Mean Squared Error) by the lead-time. This standard approach is shown in this paper to always underestimate the true lead-time demand variability, resulting in too low safety stocks and poor service. For two of the most widely applied forecasting techniques (Single Exponential Smoothing and Simple Moving Average) we present corrected expressions and show that the error in the standard approach is often considerable. The same fundamental problem exists for all forecasting techniques and all demand processes, and so this issue deserves wider recognition and offers ample opportunities for further research.

Keywords: *demand forecasting, inventory Control, safety stock*

Demand Forecasting with Four-Parameter Exponential Smoothing

Liljana Ferbar Tratar, Blaž Mojškerc, **Aleš Toman**

Faculty of Economics, University of Ljubljana, Lubjana, Slovenia

Exponential smoothing methods are powerful tools for denoising and decomposing time series, predicting future demand and decreasing inventory costs. Distinguished by their simplicity, their forecasts are comparable to the forecasts of more complex statistical time series models.

The exponential smoothing equations can be easily implemented in an Excel spreadsheet and can incorporate additive or multiplicative trend and seasonality. Optimization routines usually take a few seconds so the methods facilitate the real-time analysis and forecasting of multiple demand time series. Additive models can be applied to the series with one or several zero entries, a typical issue in modeling the demand for individual products.

The classic additive and multiplicative smoothing methods can become unreliable if the noise dominates the trend and seasonal components of the data. The smoothing equations allow the noise term of one time period to influence the smoothed series and forecasts of the future demand. The aim of our study was to develop a smoothing method that is easy to use and yields better forecasts when applied to the demand time series with several zero entries and substantial noise.

We took the standard Holt-Winters smoothing equations for the time series that exhibit additive locally linear trend and additive seasonal behavior and introduced one new smoothing parameter in the smoothing equation for the level. The gained flexibility increased the forecast accuracy substantially and reduced the costs related to the overstock and insufficient stock.

We estimated the free parameters minimizing the mean square error or mean absolute error of the one-step-ahead forecasts. The initial values for the level, slope and seasonal indices were optimized together with the smoothing parameters using the Solver optimization tool. The subsequent analyses showed that for some time series the equations for updating trend or seasonality can be omitted.

Real and simulated data sets will be used to demonstrate the improved method and its performance. The results will show that our proposed forecasting algorithm outperform the classic Holt-Winters procedure. Possible extensions to the simultaneous optimization of proposed forecasting method and stock control policy will be outlined.

Keywords: *demand forecasting, time series, holt-winters method, optimization*

On Spare Parts Demand Patterns and Their Inventory Implications

Laura Turrini, Joern Meissner

Kühne Logistics University, Hamburg, Germany

Spare parts are essential for many companies because of their central role in keeping the critical equipment up and running. Many companies or service providers need to hold spare parts inventories to minimize downtime risk and improve availability of their equipment. To find the right balance between availability and stocking costs is often very challenging due to the special characteristics of spare parts demand. That is, spare parts demand is typically slow-moving, highly stochastic, erratic and lumpy. These characteristics make the accurate predictions very difficult by standard forecasting methods (e.g., exponential smoothing) and necessitate development of new forecasting methods specifically designed for spare parts.

In particular, it has been shown by previous research that spare parts demand is generally not normally distributed, and that the best fitting distribution (mostly Gamma, Negative Binomial Distribution and Stuttering Poisson) depends on the mean inter-demand interval length, and on the squared coefficient of variation of demand sizes. As most inventory policies rely on distributional assumption of the demand, a wrong hypothesized distribution may result in unnecessary stock holdings and huge blocked capitals (as spare parts are often expensive), or in high penalty costs due to unplanned stock-outs.

We study the case of a worldwide leader in the wind-turbines market based in Germany. We analyze their weekly demand for spare parts in the last three years for over 4000 items. We use Kolmogorov Smirnov goodness-of-fit test to find the best fitting distributions to our data and compare our results to the ones of the literature. Furthermore, we implement a slightly modified K-S test that tests the right tail of the distribution only. As most inventory applications involve calculating 90%-95% percentiles of the forecasted demand distribution, the distribution of the right tail is the very crucial information that is required to implement a successful inventory management system.

An Improved Bootstrapping Method for Forecasting Spare Parts Demand using Extreme Value Theory

Rex Wang, **Sha Zhu**, Willem van Jaarsveld, Rommert Dekker

Department of Econometrics, Erasmus School of Economics, Erasmus University Rotterdam, Rotterdam, The Netherlands

Inventory control for spare parts is essential for many organizations due to the balance between preventing high holding costs and stock outs. The re-order point is an important inventory control parameter, but its estimation is difficult as the spare part demand is intermittent and only a limited history of demands is available. A well-known method is the empirical model, which uses the exact values from the demand data set to construct the lead time demand distribution. While it performs reasonably well when fill rate targets are relatively low, it has difficulties in achieving high fill rate since the empirical distribution of lead time demand fails to handle the extreme values that have not been observed. In this paper, we improve the empirical model by applying the extreme value theory, which is used to model the tail of the empirical lead time demand distribution. This empirical-tail fitting method evaluates the re-order point using both the empirical lead time demand distribution and its approximated tail. Our simulation results show that the achieved fill rate of empirical-tail fitting method is more accurate than that of the empirical model when the target is above 93%. Our findings are particularly useful in the case of expensive spare parts with high shortage cost.

Keywords: *inventory, spare parts, forecasting, extreme value theory*

Inventory Management and Modeling for Perishable Products

A Bi-Objective Chance Constrained Programming Model for Efficient Crop Harvest Scheduling

Valeria Borodin[1], Jean Bourtembourg[2], Faicel Hnaien[1], Nacima Labadie[1]

[1] *Laboratory of Industrial Systems Optimization (LOSI), Charles Delaunay Institute, University of Technology of Troyes (UTT), ICD-LOSI, Troyes, France*

[2] *Agricultural Cooperative Society in the Region of Arcis-sur-Aube, Villette-sur-Aube, France*

One of the main purposes of the agricultural supply chains management is to organize efficiently the processes of harvesting, transport and storage of the cereal production from the growing fields to the storage facilities.

The current configuration of the supply chain, where farmers can improve a continuous process of harvesting, can be enhanced by organizing a buffer crop storage (work-in-process) directly in the growing fields. Crop harvesting must be completed as soon as possible, because delayed harvest increases both the risk of yield and quality losses.

Motivated by a real life study case encountered at a typical French agricultural cooperative, this paper presents a bi-objective chance constrained programming model where the optimization criteria deal with crop quality degradation and inventory control, under climate uncertainty. Due to computational complexity and time limitations, scalarization techniques combined with $(1-\alpha)$-pertinent scenarios are used. Numerical results reported that the bi-response chance constrained approach offers a spectrum of non-dominated solutions satisfying a desired confidence level.

Keywords: *agricultural supply chain, bi-objective chance constrained optimization, inventory control*

A Satisficing Choice Model of Withdrawal Behavior of Perishable Items

Rob A.C.M. Broekmeulen, Karel van Donselaar

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

Empirical data from retail stores shows that the withdrawal behavior of perishable items from inventory by customers is neither strict FIFO nor LIFO. In our paper we model the withdrawal by the customer as the behavior of a "satisficing" decision maker who evaluates the alternatives in a given order. We fit our model on empirical data from a retail chain. We explore the implications of our model on the performance indicators waste, lost sales and remaining shelf life of the sold products with a simulation study of an inventory system of perishable items.

Optimal Piecewise-Constant Price under Heterogeneous Sensitivity to Product Freshness

Avi Herbon

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

Objective of the study: When perishable products are priced uniformly, regardless of the amount of time remaining until expiration, consumers may gravitate towards fresher products, leaving some inventory unsold. In this case, price differentiation over time can be used as a marketing tool to motivate customers to purchase all items, including those that have only a short time left until expiration. This research considers perishable products with a fixed shelf-life (e.g., pharmaceuticals, grocery products that perish when their expiration date passes, clothing that goes out of fashion at the end of the season). We develop a model for identifying an optimal (profit-maximizing) dynamic pricing policy and for evaluating the extent to which both the retailer and the consumer benefit from the implementation of a dynamic pricing policy as opposed to a static policy.

Materials and methods: We follow previous research by addressing a multiplicative demand model demand rate which decreases linearly in the selling price and polynomially over the time after replenishment, until it vanishes either at the reservation price or at expiration time. The current research considers an inventory system that consists of a storable perishable product that is periodically replenished under a demand that depends on price and on consumers' heterogeneous sensitivity to product freshness. Information about consumers' heterogeneous sensitivity to product freshness is more available to retailers nowadays than it was in the past. A key assumption of our work is that the retailer is able to utilize information on customers' heterogeneous characteristics but is unable, due to obstacles that are currently present for assigning a "personal price" especially in stores, to implement price discrimination, i.e., to charge different consumers different prices at the same point in time.

Results: Using an analytic approach we obtain necessary and sufficient conditions for the optimal solution, which are further reduced into a single equation with one variable. The mathematical analysis is supported by numerical examples that show that dynamic pricing has the potential of increasing the retailer's profits by 5.3% yet at the same time decreases consumers' freshness satisfaction by 11%-24%. The numerical illustration shows that profits are strongly influenced by the volatility of consumer sensitivity to freshness; specifically, this variable has the potential to reduce optimal profits by up to 8%.

Conclusions: Unexpectedly, it is proven that in an optimal pricing policy, the retailer should assign a lower price to fresher products and then raise the price as the products approach expiration. Another unexpected conclusion is that, in principle, aggregated demand constitutes sufficient information in order to determine an optimal pricing policy.

Keywords: *perishable inventory, price differentiation, heterogeneous sensitivity, time-dependent demand, price-dependent demand*

EPQ Models with Uncertain Production Rate: Deterioration, Lot Size Constraint and Learning Effect Consideration

Hongfu Huang, Yong He

Institute of systems engineering, School of economics and management, Southeast University, Nanjing, China

We consider the optimal inventory decisions faced by a manufacture producing and selling products in an infinite horizon with production rate uncertainty and lot size constraint. We assume that when maximum lot size is not large enough to satisfy the stock, manufacture can expend lot size by paying more money. The goal of the manufacture is to minimize the expected total average costs. EPQ models with and without deterioration are built and studied. Some propositions and algorithms to solve the model are proposed. Besides, we also studied the model considering learning effect on the production rate uncertainty. In the numerical examples, we not only derived the optimal decision variables, but also studied the influence of uncertainty and lot size threshold level to the optimal decisions and total cost. Lastly, some managerial insights are also proposed in the paper.

1. Base model: no deterioration and no capacity constraint

In this section, we model the basic EPQ inventory system when production rate is uncertain.

The inventory system is depicted in figure.

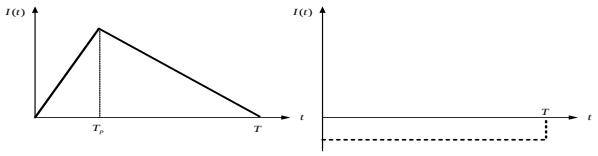


Figure 1: *Two conditions: positive inventory level and shortage*

The ordering cost per cycle is $C_o=\frac{A}{T}$,The production cost per cycle is $C_p=cd\int_d^\infty g(p)dp+c\int_0^d pg(p)dp$,The inventory cost per cycle is $C_h=\frac{h_1}{T}\int_d^\infty \frac{(p-d)dT^2}{2p}g(p)dp=T\int_d^\infty \frac{h_1(p-d)d}{2p}g(p)dp$,The shortage cost per cycle is $C_s=\int_0^d v(d-p)g(p)dp$

Total cost per cycle is $TC_{BM}=\frac{A}{T}+cd\int_d^\infty g(p)dp+c\int_0^d pg(p)dp+T\int_d^\infty \frac{h_1(p-d)d}{2p}g(p)dp+\int_0^d v(d-p)g(p)dp$

Proposition 1 The optimal time cycle to minimize the expectation of total average cost is $T_{BM}=\sqrt{\frac{2A}{\int_d^\infty h_1(p-d)d/pg(p)dp}}$

2. Model with capacity constraint

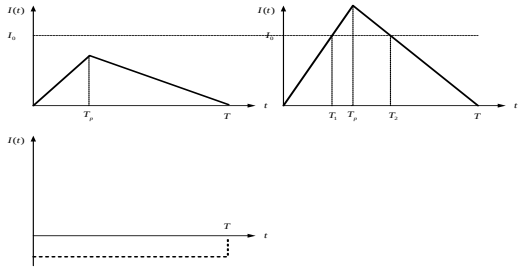


Figure 2: *Three conditions- positive inventory level with and without lot size constraint, shortage*

Here, the maximum level of producer's inventory capacity is I_0.

Proposition 2 If $h_1=h_2$ or $I_0 \geq dT$, then the problem is the same to the base model.

When $I_0<dT$, total cost per cycle is

$$TC_{CM} = \frac{A}{T} + cd\int_d^\infty g(p)dp + c\int_0^d pg(p)dp + \int_0^d v(d-p)g(p)dp + \int_d^\infty \frac{h_1(p-d)dT}{2p}g(p)dp + E[(h_2-h_1)(\frac{d(p-d)T}{2p} - I_0 + \frac{pI_0^2}{2(p-d)dT})]$$

$$-\int_0^{\Delta(T)}(h_2-h_1)(\frac{d(p-d)T}{2p} - I_0 + \frac{pI_0^2}{2(p-d)dT})g(p)dp$$

When $I_0 \geq dT$, the target function is the same to the base model.

So the final problem is to minimize the function $TC=\begin{cases} TC_{BM}, I_0 \geq dT \\ TC_{CM}, I_0 < dT \end{cases}$

Proposition 3 The target function is continuous in $T=\frac{I_0}{d}$.

Proposition 4 There exists a value of time cycle which can minimize the target function.

$$T^*_{LSCM} = \sqrt{\frac{2A+(h_2-h_1)I_0^2/d \cdot E[p/(p-d)]}{\int_d^\infty h_1(p-d)d/pg(p)dp + (h_2-h_1)d \cdot E[(p-d)/p]}}$$

3. Models for deterioration items

3.1 No capacity constraint:

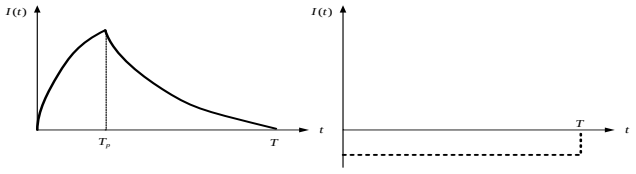


Figure 3: *Two conditions for deterioration items: positive inventory level and shortage*

Cost function $TC_{BM} = \frac{A}{T} + \frac{c}{T}\int_d^\infty pT_p g(p)dp + c\int_0^d pg(p)dp + \frac{1}{T}\int_d^\infty \frac{h_1}{\theta}(pT_p - dT)g(p)dp + \int_0^d v(d-p)g(p)dp$

3.2 Capacity constraint:

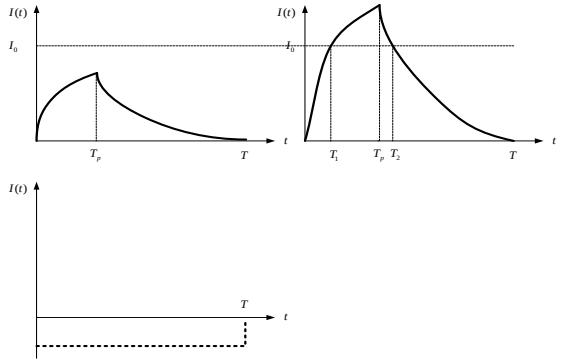


Figure 4: *Three conditions for deterioration items: positive inventory level with and without lot size constraint, shortage*

Proposition 5 If $h_1 = h_2$ or $I_0 \geq \frac{d(e^{\theta T}-1)}{\theta}$, then the problem is normalized to the no capacity constraint model.

We set $\Delta(T)=\frac{(I_0\theta+d)d(e^{\theta T}-1)}{d(e^{\theta T}-1)-I_0\theta}$, $T_p=\frac{1}{\theta}\ln\frac{p-d+de^{\theta T}}{p}$, $T_1=-\frac{1}{\theta}\ln(1-\frac{\theta I_0}{p-d})$, $T_2=T-\frac{1}{\theta}\ln(\frac{\theta I_0}{d}+1)$.

When $I_0 < \frac{d(e^{\theta T}-1)}{\theta}$ Total cost per cycle is

$$TC_{CM} = \frac{A}{T}+\frac{c}{T}\int_d^{\infty} pT_p g(p)dp + c\int_0^d pg(p)dp + \int_0^d v(d-p)g(p)dp + \frac{1}{T}\int_d^{\Delta(T)}\frac{h_1}{\theta}(pT_p - dT)g(p)dp$$
$$+\frac{1}{T}\int_{\Delta(T)}^{\infty}\{\frac{h_1}{\theta}(pT_p-dT)+\frac{h_2-h_1}{\theta}[p(T_p-T_1)-d(T_2-T_1)]\}g(p)dp$$

When $I_0 \geq \frac{d(e^{\theta T}-1)}{\theta}$, the target function is the same to the base model.

So our problem is to minimize the function $TC=\begin{cases} TC_{BM}, I_0 \geq \frac{d(e^{\theta T}-1)}{\theta} \\ TC_{CM}, I_0 < \frac{d(e^{\theta T}-1)}{\theta} \end{cases}$

Proposition 6 The target function is continuous at point $T=\frac{1}{\theta}\ln(\frac{I_0\theta}{d}+1)$.

Algorithms are designed to solve the optimization problem.

4. Models considering the learning effect on uncertainty

Under the learning effect, the uncertainty of the production rate is decreasing with time. Take the normal distribution for example, the distribution is $p \square N(\mu, \delta(\lambda t))$. Here, $\delta'(t) < 0$, $\delta''(t) > 0$, λ is the learning effect parameter, and $\delta'(\lambda) < 0$, $\delta''(\lambda) > 0$. The expectation of the distribution is $\bar{g}(p) = \frac{1}{T_p}\int_0^{T_p} g(p,t)dt$. So the new problem is to minimize the function

$TC(T)=\begin{cases} TC_{BM}, I_0 \geq \frac{d(e^{\theta T}-1)}{\theta} \\ TC_{CM}, I_0 < \frac{d(e^{\theta T}-1)}{\theta} \end{cases}$ where,

$$TC_{BM}(T) = \frac{A}{T} + \frac{c}{T}\int_d^\infty pT_p\bar{g}(p)dp + c\int_0^d p\bar{g}(p)dp + \frac{1}{T}\int_d^\infty \frac{h_1}{\theta}(pT_p - dT)\bar{g}(p)dp + \int_0^d v(d-p)\bar{g}(p)dp$$

$$TC_{CM}(T) = \frac{A}{T} + \frac{c}{T}\int_d^\infty pT_p\bar{g}(p)dp + c\int_0^d p\bar{g}(p)dp + \int_0^d v(d-p)\bar{g}(p)dp + \frac{1}{T}\int_d^{\Delta(T)} \frac{h_1}{\theta}(pT_p - dT)\bar{g}(p)dp + \frac{1}{T}\int_{\Delta(T)}^\infty \{\frac{h_1}{\theta}(pT_p - dT) + \frac{h_2 - h_1}{\theta}[p(T_p - T_1) - d(T_2 - T_1)]\}\bar{g}(p)dp$$

5. Numerical examples and managerial insights

The numerical examples and managerial insights will be presented in the final paper.

Combination Sale Problem for a Perishable Product

Hiroaki Ishii

Department of Mathematical Sciences, School of Science and Technology, Kwansei Gakuin University, Sanda, Japan

Several researchers have been interested in inventory control for a perishable product such as blood, fresh fruit, milk, film, vegetable etc. Here we introduce a combination sale in order to reduce the outdating quantity and consider the following model.

(1) Single perishable product with two life time period is considered. That is, for a period, an amount of old one (remaining life time period is 1) in the stock is given as x_2 and under this condition that we should determine an ordering quantity x_1 of the fresh one (remaining life time period is 2) and unit price r_B of combination sale.

(2) Ordering takes a place at the start of the period. The unit purchasing cost of the product is *c*.

(3) Issuing policy is LIFO, that is, customer buys fresh one first and if fresh one is sold out, only some percent of customers overflowed from purchase of the fresh one buy the old one. We assume that this percentage is at most 100q. unit price of the fresh one is r_1 and that of old one is r_2.

(4) Prominent feature of our model is a combination sale, that is, we sell a set of products consisting of the fresh and old one and it is sold at the discount unit price r_B less than the sum of r_1 and r_2. We assume at most 100p percent of the customers purchasing the fresh one accept the combination set, that is, buy the old one with the fresh one at the same time where we assume that p>q and. p is the decreasing function of r_B.

5) The old one that is not purchased by the customer outdates and is discarded at the unit cost θ. The fresh one not purchased by the customer is stocked at the unit cost *h*. While if amount of the fresh one is not enough to cover the demand of customer, then shortage cost *s* is incurred at unit shortage.

(6) The demand D of the customer is a nonnegative random variable. Its cummulative distribution function and density function are F(D) and f(D) respectively where F(0)=f(0)=0.

Under the above setting, we calculate an expected profit function $E(x_1, r_B)$.

Since r_B, x_1 are independent each other, first we fix $r_B = \bar{r}_B$ and maximize $E(x_1, \bar{r}_B)$. For that purpose, $E(x_1, \bar{r}_B)$ is divided two parts, that is, $0 \le x_1 \le \frac{x_2}{p}$ and $x_1 \ge \frac{x_2}{p}$. Then we show $E(x_1, \bar{r}_B)$ is concave in either part. Then we investigate an optimal ordering quantity of $E(x_1, \bar{r}_B)$ depending on the conditions of prices, costs and parameters p, q.

Based on the result of $E(x_1, \bar{r}_B)$, that is, the case that price of combination sale is fixed, maximized value of $E(x_1, \bar{r}_B)$ is maximized by changing $\bar{r}_B$.. For that purpose, we optimize p since p is a decreasing function of r_B under the condition $r_1 \le r_B \le r_1 + r_2,\ p(r_1) = 1, p(r_1 + r_2) = 0$. We show $E(x_1, r_B)$ is concave function of r_B for the fixed x_1 Finally we discuss many further research problems including a more suitable combination sale and customer preference between price and freshness.

Keywords: *perishable product, combination sale, expected profit function, optimal ordering quantity, optimal cost of combinatorial sale*

Continuous Review Joint Replenishment System for Perishable Items with Random Lifetime

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

[1] *ESC Rennes School of Business, Rennes, France*
[2] *KEDGE Business School, Bordeaux, France*
[3] *Ecole Centrale Paris, Chatenay-Malabry, France*
[4] *TUM School of Management, Munich, Germany*

This paper considers the continuous review can-order (s;c;S) policy to coordinate thereplenishment of multiple perishable items with random lifetimes. An iterative procedure is proposed to solve the joint replenishment problem for perishable items under positive lead time. We investigate the impact of perishability and cost parameters on the performance of the can-order policy. Finally, the performance of the can-order policy we propose is compared to the optimal periodic review (s;S) policy under various cost parameters.

Keywords: *perishable items, joint replenishment, continuous review*

The Supply Chain Design for Perishable Food with Stochastic Demand

Shuai Yang[1], **Chulung Lee**[2]

[1] *School of Management, Harbin University of Commerce, Songbei District, Harbin, China*
[2] *School of Industrial Management Engineering and Graduate School of Management of Technology, Korea University, Seongbuk-gu, Seoul, Republic of Korea*

With the high pace of modern life, more and more people are used to buying perishable food in marts or retail groceries for convenience. Perishable food becomes an important factor that customers choose one retail store from others (Wang and Li, 2012). The increasing demand for perishable food brings about more profit, and meanwhile larger quantities and more variety make the food supply chain more difficult to manage. The deterioration and demand uncertainty of perishable food result in large scale of spoilage and frequent shortages during the perishable food is being sold in retail stores. The attrition rate of perishable food reaches as high as 15% in retail stores and hence causes costs of billions of dollars in European groceries (Ferguson and Ketzenberg, 2006; Karkkainen, 2003), which is far from satisfactory. The mass spoilage and difficulty in management impel retailers to set a relatively high price, which retains the consumption and results in frequent shortages. The development of modern identification and sensory technologies, such as temperature and humidity sensors and RFID technology, could monitor and track the ambient environment and consumption continuously. These technologies make it possible for managers to establish an agile supply chain and hence improve the management of perishable food. Since the decaying quality of perishable food leads to a demand slowdown, food retailers usually apply some promotion strategies to improve the efficiency of the food supply chain. Discounting may increase the consumption rate when food's quality decays, for most kinds of perishable food' demands are price-sensitive. Meanwhile, larger shelf space may attract more customers, so a reasonable allocation of shelf space could improve the utilization of shelf space and result in additional profit. Therefore, in this research, we first considers pricing strategy, shelf space allocation, and replenishment policy to maximize the retailer's total expected profit with stochastic demand for a single-item food supply chain. It is proved that there is an optimal solution for the food supply chain design. Furthermore, we extend the single-item supply chain problem into a multi-item problem, and provide a simple searching algorithm to obtain the optimal allocation of shelf space among these items. Finally, the results are illustrated by some numerical data.

Keywords: *food supply chain, shelf space allocation, deterioration, pricing strategy, stochastic demand*

Order Policies for a Perishable Product with non-Stationary Demand Under a Fill Rate Constraint

Karin G.J. Pauls-Worm[1], Eligius M.T. Hendrix[2], René Haijema[1], Alejandro G. Alcoba[2], Jack G.A.J. van der Vorst[1]

[1] *Wageningen University, Operations Research and Logistics Group, Wageningen, The Netherlands*
[2] *Universidad de Málaga, Computer Architecture, Málaga, Spain*

We study the practical problem of a producer of a fresh food product with a long lead time who has to decide every period (e.g. week) how many items of a product to produce. The producer has multiple batches of the same product of different ages in production, so there are multiple outstanding orders. When a batch is ready for use, the product has a fixed life time. At the end of the life time, the product becomes waste in the sense that it cannot be used anymore to be sold with the aimed quality. It still may be used for other purposes, so it may have a salvage value.

These characteristics apply in more or less the same way for e.g. the maturation of cheese, meat from breeding to slaughtering and crops from seed to harvesting. The demand for (fresh) food products is uncertain, so the production quantity has to be determined based on forecasts. A complicating factor is that demand is highly fluctuating, mainly caused by price promotions of the retail organisations. So demand is non-stationary. In addition, a fill rate service level constraint applies.

We investigate a model where the timing and quantity of the production are fixed in advance for a finite time horizon. To minimise waste, one issues the oldest product first, i.e. a FIFO issuing policy. In case of out-of-stock, sales is lost. The objective of our study is to develop order policies for a perishable product with non-stationary demand and a long deterministic production lead time, that approximately meet service level constraints while keeping outdating low.

Keywords: *production-inventory planning; long lead time; perishable product; non-stationary stochastic demand; fill rate constraint*

Food Waste in Retailing and Wholesaling – Drivers, In-store Logistics Processes and Reutilisation

Gerald Reiner[1], Christina Holweg[2], Christoph Teller[3]

[1] *Faculty of Economics and Business, University of Neuchâtel, Neuchatel, Switzerland*
[2] *Institut fuer Handel und Marketing, Vienna University of Economics and Business, Austria*
[3] *Surrey Business School, University of Surrey, United Kingdom*

The phenomenon of edible food waste in supply chains has become an increasingly contentious issue, partly due to the current economic crisis and the consequent wider societal backdrop of impoverished food consumers. Nevertheless, insights into food wastage in distribution (namely retailing and wholesaling) remain limited.

The aim of this paper is to(1) identify the different types of (un-/edible) food waste in different store formats, (2) investigate the core drivers of food waste occurrence, and (3) explore opportunities to reduce and reuse food waste. Based on the in - store logistics and retail operations literature, a conceptual framework is developed and used for case study research involving 33 cases across all dominant formats (i.e. supermarkets, hypermarkets, discount stores, convenience stores and wholesales stores).

The case study research methodology comprises in-depth interviews with store-and category managers, point of sale observations and secondary data research (e.g. from EPOS systems). The case study data are used to analyse how different inventory management policies, reutilisation processes and service level requirements together influence inventory obsolescence costs .

The case analyses reveal six product categories responsible for producing most of the in -store food waste. The main reasons that drive wastage are inappropriate order policies, store and shelf replenishment failures, unpredictable fluctuations in demand and inadequate handling of products by staff and consumers. Depending on the type of food waste, we identify nine processes related to the disposal, recycling or the redistribution of edible food waste. Dynamic modelling indicates the impact of different inventory replenishment policies and order quantities on inventory obsolescence costs. The latter mainly corresponds to the overall profit margin. Reduction in edible food waste provides significant financial performance and, the potential for improved competitiveness.

This paper provides an in-depth understanding of processes and policies that lead to food waste in distribution and to reveal opportunities for reduction of edible food waste as well as to establish redistribution channels for edible food waste. The contribution is thus to provide pathways for more efficient in -store operations and present opportunities to strengthen the corporate social responsibility of retailers and wholesalers.

Keywords: *in-store logistics, dynamic analysis, case study research, food waste, inventory obsolescence costs*

Smart Inventory Allocation Policies in Smart Electricity Meter Installation Projects

Behzad Samii

Technology and Operations Management Area, Vlerick Business School, Brussels, Belgium

The original motivation of this research has been the management of inventory of smart electricity meters in a large scale European implementation project. The Distribution System Operator (DSO) is facing two competing objectives. The DSO is interested in priority installation of the smart meters for high consuming customers with high variability in demand. This demand class pose the highest risk of grid disruption and should be monitored/controlled with highest priority. On the other hand, the low priority customers are also interested in prompt installation of smart meters in their premises due to potential cost savings opportunities resulted from their own corrective actions; to smoothen consumption patterns during peak periods by being better informed and in (almost) real time. However, due to fast changing technology of smart meters, the DSO carries limited inventory of current technology smart meters (for a "campaign", about six-month worth of installation activities) whereas the implementation project can take as long as ten years. Therefore, the policy of allocating the available inventory of meters to candidate high/low priority customers should maximize demand fulfillment for both customer classes with minimum wasted inventory at the end of any given campaign.

Due to incomplete information about the type of customers a priori, we use mathematical modeling taking into account the stochastic nature of low/high priority customer arrivals. Although measuring the long term cost of unfilled demand for any demand class is extremely difficult, we found it practical to quantify the importance of one customer class relative to another. We assume that some partial information regarding the bottom line impact of a shortage in one customer class compared to the other can be conjectured. If we choose to reserve inventory for high priority demand class, the (cost-based) benefit of this reservation can then be calculated for all feasible reserved quantities and the optimal reserved quantity identified. We derive closed form expressions for the expected fill rates and the expected number of units short in each demand class under both standard and theft nesting allocation mechanisms. This research is completed with a numerical analysis section to illustrate our approach in a small scale setting. Overall, this study provides important insights into how decision makers can efficiently manage perishable products supply chains with heterogeneous service requirements.

Keywords: *service differentiated supply chains, smart meters inventory management, inventory allocation policies, inventory rationing, nested allocation mechanisms*

A Perishable Economic Lot-Sizing Problem with Stationary Production Capacities

Zeynep Sargut, Gul Isik

Industrial Engineering, İzmir University of Economics, Izmir, Turkey

In this study, we consider a producer that needs to satisfy the demand of a single perishable product over a finite horizon. We try to identify the optimal production, inventory and backlogging decisions over the horizon, where the parameters of the problem are deterministic but changing over time. Moreover, producer has a stationary production capacity that limits the production amount at each period and is allowed to backorder the unmet demand later on. All cost functions are concave and backlogging and holding cost functions are age dependent, which are more realistic for perishable items. Under these conditions, demand satisfaction will not always be "first produced will be first consumed" manner. Therefore, the production amounts are not enough to determine the inventory levels; we also need to decide how to distribute a production among the demand periods. We prove that the optimal solution has a sub-component structure therefore dynamic programming approach is possible. We also identify the properties of the sub-components and propose an approximation scheme to solve the problem.

An analysis of a Two-Stage Perishable Product Supply Chain with Service Level and Shelf Life Agreement

Sandra Transchel

Kuehne Logistics University, Hamburg, Germany

Incentive alignment of different parties in a supply chain is still a fundamental challenge. Driven by high fixed cost, manufacturers/suppliers aim to produce/order larger lot sizes in order to leverage economies of scale. Retailers, on the other hand, tend to stock fewer units more frequently in order to respond more flexibly to unexpected demand changes. This misalignment of incentives becomes even more critical if the supply chain manages a perishable product. A product is assumed to be perishable if it has a finite shelf life, i.e., it expires after a certain period of time. When manufacturers sell their products to retailers they have to make sure to keep inventories with a certain remaining shelf life that retailers accept. If the remaining shelf life is too low, manufacturers would face the risk that retailers do not accept these products, even though they are not expired. Due to this perishability manufacturers are not be able to fully leverage economies of scale.

We study a two-echelon supply chain with a manufacturer and a retailer that sell a single product with a fixed limited shelf life. The manufacturer and retailer negotiate a contract including a wholesale price, a minimum service level requirement that the manufacturer needs to achieve (service level agreement), and a minimum remaining product shelf life that the manufacturer needs to deliver (shelf life agreement). The retailer, in turn, has to guarantee a predetermined service level. The manufacturer faces fixed manufacturing cost and aims to leverage economies of scale by producing larger lot sizes, however, subject to the shelf life agreement with the retailer that guarantees a minimum remaining shelf life. Due to the service level agreement the retailer cannot expect that manufacturer always delivers the order on time in full.

We develop and study an inventory control model and a supply chain contract where both manufacturer and retailer follow a periodic review policy. We investigate the interaction of service level and shelf life agreements with respect to its impact on average profits and average obsolescence of the manufacturer, the retailer, and the whole supply chain. We first develop and analyze a rather stylized supply chain inventory control model and provide structural properties. To provide more detailed insight we present results of a numerical study. We show how service level and shelf life agreement affect supply chain efficiency, i.e., the supply chain performance in comparison to the performance of a centralized decision-maker.

Keywords: *inventory management, perishable products, supply chain contracts, service level agreement, shelf life agreement*

Inventory and the Environment

Sustainable Supply Chain with Joint Constraints of Carbon Emission and Environment Carrying Capacity

Huiping Ding, Qilan Zhao, Jia Xu

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

During the past decade, carbon emission associated with economic development has caused severe issues, such as global warming, green house effect and abnormal climate. 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). Carbon emission and pollutant reductions are particularly interconnected with business behavior of supply chain. How supply chain members would collaboratively deal with environmental and social issues such as carbon emissions and pollution has attracted high attention worldwide. Obviously, there are a number of questions which should be addressed in this domain. One of the crucial issues in supply chain management is to trade off the economic objective and environmental sustainability, for instance, maximizing profit of a supply chain system as a whole together with unifying interests of the members, and meanwhile jointly meeting the constraints of carbon emission and environment carrying capacity. This paper focuses on investigating the mechanism of having the supply chain members collaboratively reduce carbon emission and pollutant based on investing in producing environmental friendly product (EFP) which have impact on supply chain profit allotment.

In this paper, based on the assumption that cooperation in supply chain can collectively reduce both carbon emission and pollutant, a collaborative supply chain decision framework is structured with joint constraints of carbon emission and environment carrying capacity, where the objective is to maximize the net present value of the integrated supply chain together with satisfying the interests of individual members in terms of profit allotment. The problem formulation incorporates VMI model to facilitate inventory replenishment process between supply chain members. A problem solving framework is proposed for motivating the supply chain members to cooperate each other to reduce carbon emission and pollutant collectively. Through analyzing impact of environment constraint on business behavior, the research intends to delve into the factors influencing the collective interest of the supply chain and the individual interest of the members, and probes into how to properly share the collaborative benefits gained from collaboration of joint reductions of carbon emission pollutant reductions with the view of Rubinstein game approach. Based on the analytical work aforementioned, a numerical analysis is provided to illustrate the model.

The results show that the members' collaboration plays a crucial role in the improvement of supply chain's collectively environmental performance, and there exists an equilibrium transfer price that satisfies the supply chain members meanwhile the carbon emissions and pollutant are in compliance with the constraints. We can draw the conclusion that, with tightening the environment constraint, the members' collaboration plays a crucial role in the improvement of supply chain's environmental performance in terms of collectively reducing carbon emission and pollutant, both the members and the system as a whole can gain more profits than non-cooperation while the individual interest and collective interest are unified.

Our key contribution lies in the model of supply chain decision making based on fulfilling the both constraints of carbon emission and pollution. Our research findings have the following implications. First, considering that the supply chain cooperation is necessary for effectively reducing carbon emission and pollutant the government's supervision should have incentives to motivate the cooperation between the members. Second, owing to the nature of being willing to individually maximize their own benefit the supply chain members often intend to fully use the constrained environment tolerance when the constraints are set tight. Third, through the members' cooperation the constrained total environment tolerance can be collectively used for helping to improve both the environmental and business performances of the supply chain system. Therefore, the supply chain cooperation should not only have both the individual interest and the collective interest unified but also be in compliance with the environment constraints more effectively.

***Keywords**: supply chain, carbon emission, environment carrying capacity, collaboration, profit allotment*

References:

Chaabane, A., Ramudhin, A., Paquet, M., 2012. Design of sustainable supply chains under the emission trading scheme. International Journal of Production Economics 135, 37-49.

Diabat, A., Simchi-Levi, D., 2009. A Carbon-Capped Supply Chain Network Problem. IEEE International Conference on Industrial Engineering and Engineering Management. 523-527.

Ding, H., Guo, B., Liu, Z., 2011. Information sharing and profit allotment based on supply chain cooperation. International Journal of Production Economics 133, 70–79.

Druckman, A., Bradley, P., Papathanasopoulou, E., Jackson, T., 2008. Measuring progress towards carbon reduction in the UK. Ecologic Economics 66, 594–604.

Ge, J., Huang, P., 2008. Price decision analysis for closed-loop supply chain based on game theory. Journal of Systems Engineering 23, 111-115.

He, D. Ma, H., 0211. Strategy of Enterprise Production and Store under Carbon emission constraints. Resources & Industries 13, 63-68.

Liu, Q., Ding, H., 2012. Research on collaborative pricing decisions of enterprises in supply chain under constraints of carbon emission. In: Proceedings of International Conference on Low-carbon Transportation and Logistics, and Green Buildings, LTLGB2012, Beijing, China, October.

Ramanathan, U., Gunasekaran, A., 2012. Supply chain collaboration: Impact of success in long-term partners. International Journal of Production Economics, In Press, Available online 12 June.

Sommerville, M., Jones, J.P.G., Rahajaharison, M., Milner-Gulland, E.J., 2010. The role of fairness and benefit distribution in community-based payment for environmental services interventions: A case study from Menabe, Madagascar. Ecological Economics 69, 1262-1271.

Sundarakani, B., Souza, B., Goh, M., Wagner, S.M., Manikandan, M., 2010. Modeling carbon footprints across the supply chain. International Journal of Production Economics 128, 43–50.

Zhang, B., Xu, L., 2013. Multi-item production planning with carbon cap and trade mechanism. International Journal of Production Economics, In Press, Available online 31 January.

Zhang, W., 2011. Game Theory and Information Economics, 1st edition, Oversea Publishing House, 122.

Sustainable Supply Chain Coordination

Adel Elomri, Shaligram Pokharel

Qatar University, Doha, Qatar

In this paper, we present a model for analyzing the impact of carbon emission considerations when coordinating operations between two independent business units: a buyer and vendor. In this setting, we examine how the values of model parameters as well as the considered regulatory emission control policies affect both costs and emissions. Under carbon emission considerations, we show that contrary to what one might think, individual efforts towards reducing carbon may lead to increase the total supply carbon emissions. In this context, coordinating the supply chain might not be the suitable solution to mitigate carbon emissions, for instance we show that the coordinated solution remains profit-optimal but not necessarily emission-optimal. We identify conditions on cost and emission parameters under which the joint policy is both profit and emission optimal.

Analysis of Issues Controlling the Feasibility of Automobile Remanufacturing Business in India

Ajay Sinha[1], Sandeep Mondal[2], **Ram Ganeshan**[3]

[1] *Indian School of Business, Mohali, India*
[2] *Indian School of Mines, Dhanbad, India*
[3] *College of William & Mary, Williamsburg, United States*

Remanufacturing is a business option where used and discarded products are converted to a usable product or component after a series of value additive operations. In the last three decades, it has grown into a significant business sector in developed countries. Take-back obligations, disposal bans, economic benefits, creation of stock of components/parts from disassembly and demand for spare parts during post product life cycle period are key enablers of the growth for this business sector. In India, remanufacturing business is mostly practiced as disorganized sector. Though Indian automobile industry holds tenth position in the entire world, second in two wheelers and fourth in commercial vehicles, there are no significant initiatives either form the government or from the industry to consider remanufacturing as a separate business entity. In this paper an empirical investigation is carried out among the Indian automobile companies to explore the reasons behind non-acceptance of remanufacturing as a profitable business option. The survey identifies critical issues that impact the feasibility of automobile remanufacturing in India. The survey also identifies the differences in the perception on remanufacturing by different players in the automobile supply chain i.e., HCVs, LCVs, car, two wheeler or OEMs & suppliers.

Keywords: *remanufacturing, automobile, empirical study, India*

Old Lamps for New: Choosing Freight Modes with a Carbon Emission Target

Tonya Boone, **Ram Ganeshan**

Mason School of Business, College of William & Mary, Williamsburg, United States

The fourth assessment of the Inter Governmental Panel on Climate change (IPCC) reports that:

"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level."

Since the 1750s, atmospheric concentrations of carbon dioxide have risen from about 280 to 379 parts per million (ppm) in 2005. This increase is largely the result of large-scale supply chains to sustain modern economies and lifestyles. Big contributor to greenhouse gases (GHG) emissions are energy use to run industrial processes, generate electricity, transport goods, and heat and cool residential and industrial structures. To mitigate the effects of global warming, the IPCC estimates that emissions to be reduced by 50% by 2050 and by 80% by 2080. Significant opportunities exist in reducing the carbon intensity in supply chains and by reexamining common decisions that supply chain managers often make, we can provide strategies and policies to reduce the carbon footprint of the product.

Decisions on the amount of inventory to hold and the freight mode to use significantly impact the carbon footprint of the product. In this paper, we focus on the choice of the appropriate transport mode. This inventory-transportation trade-off is a well-studied problem in the literature – however only recently have carbon constraints been part of the framework. Slower transport modes like inland waterways and ocean freight are cheaper and likely have a lower footprint to transport but also necessitate higher cycle and safety stocks, making inventory costs (and the corresponding carbon intensity) higher. On the other hand, faster modes like LTL shipping are quick, warrant lower stock but are expensive and have, on average a higher carbon footprint to transport. Deciding on the appropriate mode to us is a tradeoff between the uncertainty of demand and lead time, the cost and carbon intensity of the transport mode and the product, and the constraints on service and carbon emissions. This paper presents a comprehensive inventory-transportation framework to explore these trade-offs. This paper builds on existing literature in this area by using a comprehensive cost framework encompassing cycle, safety, in-transit inventory cost, in addition to purchase and the actual cost of transportation. Our model uses a stochastic demand and lead-time setting providing a realistic framework for deciding on mode choice.

Recovery Inventory Control and Environmental Mechanisms

Marthy S. Garcia-Alvarado, Marc Paquet, Amin Chaabane

École de Technologie Supérieure, Montreal, Canada

We examine a recovery inventory problem subject to a cap-and-trade scheme. The system operates under a periodic-review process modeled in discrete time and subject to random demand and returns. Demand can be satisfied by two sources. The primary source, remanufacturing, is environmentally friendly but expensive, whereas the second, manufacturing, is more cost effective, but with negative environmental consequences. The problem is formulated as a stochastic dynamic model, and solved by a genetic algorithm. A sensitivity analysis is performed to identify the impact of carbon allowance prices, emission-cap and other environmental factors in the decision- making process. The results indicate that there is an emission-cap range in which the inventory policy can help to overcome environmental constraints. Moreover, if the carbon allowance price is such that the environmental benefit absorbs the cost of less polluting technology, a change in the inventory policy must be made.

Introduction: The stringency of environmental regulation has become a major concern for many companies. In this context, several authors have demonstrated that logistics activities play a key role in reducing an organization's negative environmental impact. Therefore, decision-making models should be improved in order to take into account environmental parameters and to optimize inventory costs. There exists a range of possibilities for a model integrating environmental concerns and logistics, including two approaches studied by researchers: 1) end-of-life product recovery and 2) greenhouse-gas reduction. This paper is inspired by the previous work of Ahiska and King (2010), and additional environmental constraints. Moreover, we contribute to the understanding of the role of inventory control on emission reduction, by establishing a carbon management policy, and analyzing the impact of inventory control on improving the environmental performance of a company.

Problem Description: We consider a stochastic closed-loop system subject to two environmental constraints. In a cap-and-trade mechanism, a number of carbon allowances (emission-cap) is allocated to a firm. The company can purchase or sell allowances on the trading market. On the other hand, under a minimal remanufacturing requirement policy, at each period, a minimal quantity of returns must be remanufactured.

The system is a periodic-review process modeled in discrete time. The system has two stock points 1) remanufacturable and 2) serviceable. The remanufacturable inventory is replenished by returns. Demand is satisfied by the serviceable inventory which can be replenished by manufacture and remanufacture. Returns and demands in each period are independent, non-negative, and discrete random variables. Backlogging is allowed up to a maximum quantity. When unfilled demand exceeds the maximum quantity, sales are lost. Manufacturing and remanufacturing have a production capacity. Lead-time for both activities is a single-unit period, i.e., orders raise serviceable inventory at the end of periods. The remanufacturing and manufacturing costs are stationary and comprise a fixed and a quantity-related production cost. There is also an environmental impact associated with each activity. The problem is formulated as a stochastic dynamic model. At the beginning of each period, the inventory levels are reviewed. Then, the following decisions are made 1) quantity to manufacture, 2) quantity to remanufacture,

3) the number of allowances to purchase, and 4) the number of allowances to sell. The aim is to determine the optimum replenishment policy and carbon management strategy to minimize the total cost over the full horizon length.

Resolution Method: The studied case is a combinatorial optimization problem, where at each planning period a set of decisions must be made. Since there are many choices for the decision, the function is characterized by multiple global and local optima. Using dynamic programming, the number of iterations required for obtaining the optimal solution depends on the state and the solution space. Thus, we develop a genetic algorithm (GA) to study larger instances. Genes of our GA are real-coded, and chromosomes consist of an array of length equals to the total number of decisions to be made over the planning horizon. An initial population is generated randomly. The fitness of each individual is evaluated by the reward function. After population initialization, reproduction actions follow. Reproduction begins by choosing two random individuals for a one-point crossover. For each pair of parents selected, one offspring is built. Offspring can be mutated with three equally probable mutations. The choice between the set of mutation operators is random. After reproduction, the new generation is built based on the fitness values and the preservation of diversity. The GA stops when any of the stop criteria is met: 1) the number of maximum iterations has been reached, or 2) the fitness value has not improved for G times.

Numerical Examples: A sensitivity analysis is conducted focusing on the influence of the carbon allowance price, the emission-cap, the minimal remanufacturing quota, and allowance trading over the environmental performance. The numerical examples are built based on the literature and the California Cap-and-Trade Program. The results indicate that when there is no possibility of trading allowances, the effectiveness of changing the inventory policy is dictated by the emission-cap values. In general, within a specified emission-cap range, modifying the inventory policy helps to ensure compliance with the emission-cap strategy. Above the range, the emission-cap is too loose, and changing the inventory policy would result in a loss of money. On the other hand, below the range the emission-cap is severe; a change of the inventory policy is not enough, and the service level falls rapidly. In the case that allowance trading is permitted, decisions are made according to the emission-cap and allowance price. Decision-making is mainly driven by the factor exercising greater force over the system. When the environmental benefit covers the cost of greener technology, the inventory policy is changed, encouraging the least polluting activity. Meanwhile, when the environmental benefit is low according to the processes' costs, the emission-cap will be highly significant and, if severe, the inventory policy is modified; otherwise a change is not economically advantageous. The minimal remanufacturing requirement forces the system to integrate remanufacturing into its activities, modifying the inventory policy. Nevertheless, the quantity remanufactured is only the minimum. This policy is easily applied, but the cost associated with it is higher than that of another environmental mechanism. Hence, given the different strategies' costs, it is more economically advantageous to the company to integrate the cap-and-trade scheme, where the company can have a financial benefit from accounting for and reducing its emissions.

Conclusions: Each year, the allowance price becomes costlier and the emission-cap shrinks. This work provides strong evidence supporting that inventory policy helps to determine the trade-off between cost and pollution in order to remain legal and minimize cost. Clearly, there is a point where the inventory policy will no longer help with the carbon abatement policy, necessitating a major investment in technology. However, during the period that a company is managing

reducing its environmental impact while minimizing cost, inventory control gives the company flexibility to balance the amount to manufacture and remanufacture in order to meet demands and satisfy the emission-cap for a longer time. This study might be a source of motivation for companies that are still not accounting for their emissions.

Keywords: *inventory control, cap-and-trade, closed-loop systems, genetic algorithms*

References:

Ahiska, S. S., andRussell E. King. 2010. Inventory optimization in a one product recoverable manufacturing system. International Journal of Production Economics, vol. 124, no 1, p. 11-19.

On the Use of Waste Energy in a Two-Stage Production System with Controllable Production Rates

Konstantin Biel, **Christoph H. Glock**

Carlo and Karin Giersch Endowed Chair "Business Management: Industrial Management", Technische Universität Darmstadt, Darmstadt, Germany

According to the U.S. Energy Information Administration, industrial energy consumption, which is one of the four major end-uses of energy (i.e., residential, commercial, industrial, and transportation energy), accounted for 32 percent of the overall energy consumption of these four end-uses in 2013. Manufacturing is thereby responsible for the majority of energy that is consumed in industry.

For this reason, research on the coordination of production systems has started to consider energy-related aspects in recent years. This paper contributes to this emerging stream of research by studying the role of waste energy in the coordination of production systems. More specifically, it considers a situation where industrial waste heat can be converted into electricity, which, in turn, can be used to support running the production stages. This paper investigates how lot sizing policies change if waste energy is used to operate the system, and pays special attention to the scheduling of interruptions between production runs and the determination of optimal production rates.

The results of the paper indicate that using waste energy resulting from production reduces the overall energy requirements of a production system. The inventory policies developed in this paper support an efficient use of waste energy.

Keywords: *waste energy, two-stage production system, energy costs, batch sizing, variable production rate*

Information Sharing in a Sustainable Supply Chain

Mehmood Khan, Matloub Hussain, Hussein M. Saber

College of Business Administration, Abu Dhabi University, Abu Dhabi, United Arab Emirates

The industry around us is getting immense pressure as the society goes more and more conscious about making this world sustainable. It is not only about having a lesser contribution in climate change but about keeping their reputation intact in a competitive market, as well. This inclination can be easily observed in the contemporary literature on supply chains. A huge number of researchers have recently attempted to model different aspects of sustainability in a supply chain, e.g. supplier selection, transportation modes and carbon footprint etc.

Though the researchers and academics focus on triple bottom line (economic, environmental and social) for measuring sustainability indicators of a supply chain, none has yet formulated an analytical definition of the social cost. This social cost may be in the form of several indicators such as (*i*) work hours of employees and/or (*ii*) total energy consumed through the lifecycle of a product. Besides, there is a dire need to explore the benefits of partial or complete information sharing [2] in a sustainable supply chain, as the stakeholders are so concerned about utilization of resources. This would not only enhance the stock level throughout the supply chain but would reduce the emissions in storage, transportation and disposal, as well. Thus, this paper would be the first to address these additional criteria to inventory and supply chain modeling.

Battini *et al.* [1] have recently provided a sustainable EOQ model for a buyer, by incorporating environmental concerns to the traditional EOQ model. They investigated the environmental impact of a number of transportation factors such as location of vendor/supplier and freight vehicle utilization ratio. They applied this model to a real industrial case and found that an intermodal transportation is more beneficial than a mono-modal road transportation.

In this paper, an extension to the work of Battini *et al.* [1] is presented to incorporate social cost and information sharing in a two level supply chain. Different aspects of the social cost will be incorporated and the benefits of partial and complete information sharing will be studied through sensitivity analysis [2]. An immediate extension to this work would be to study the benefits of information sharing in a multi-tier supply chain.

Keywords: *supply chains, sustainability, triple bottom line, information sharing*

References:

[1] Battini, D., Persona, A. and Sgarbossa, F., 2014. A sustainable EOQ model: theoretical formulation and applications. International Journal of Production Economics, 149, 145–153.

[2] Lee, H.L., So, K.C. and Tang, C.S., 2000. The value of information sharing in a two-level supply chain. Management Science, 46(5), 626–643.

Hierarchical Transportation Scheduling in Herbaceous Biomass Supply Chains

Judit Nagy[1], László Torjai[2]

[1] *Department of Logistics and Supply Chain Management, Corvinus University of Budapest, Institute of Business Economics, Budapest, Hungary*

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

Objective of study: Developed countries put even more emphasis on making use of renewable energy resources. From the wide range of renewable energy resources we focus on herbaceous biomass – the one particularly important in Hungary – and analyse the supply chain which deliver the feedstock from biomass producers to a biorefinery (upstream chain). First, we reveal the competitive priorities relevant to herbaceous biomass supply chain (HBSC), that is, we identify the strategic focus of its operations. Second, we operationalise them and define how they influence the transportation scheduling decision situation. In order to be able to optimise the above problem we break it down into three parts: (1) transportation scheduling for the planning horizon, (2) transportation allocation to depots, (3) detailed scheduling within a day.

***Materials and methods*:** We conduct a literature review on applicable competitive priorities and their relationship To define competitive priorities for HBSC we rely on some basic supply chain management theories like Fisher's (1997) and Lee's (2002) supply chain typology. By using case study method, we analyse the transportation scheduling decision situation of a biomass-fired power plant and its supply chain located near Pécs, Hungary.

Results: The results of the research are twofold. First, we have concluded that HBSC has to be a physically-efficient supply chain being able to handle supply uncertainty. We have found that HBSC has to focus on competitive priorities like sustainability, cost-efficiency, reliability both in feedstock volume and quality, as well as flexibility to be able to adapt to unexpected events. We have also identified supportive capabilities like information sharing, innovation and collaboration. Second, we have worked out a three-part decision making sequence for transportation scheduling among depots and the biorefinery. For the individual decision models we have defined objectives and constraints which result from the competitive priority structure.

Conclusion: Not only organisations but supply chains also have to identify competitive priorities, which are determined by their possessed organisational capabilities and the business environment. However, these elements of the business strategy should be discovered on operational level, too, while making detailed decisions. In this paper we demonstrate how to operationalise competitive priorities of the herbaceous biomass supply chain in the case of a particular decision situation.

Keywords: *transportation scheduling, supply chain, herbaceous biomass, competitive priority*

References:

Skinner, CW. Manufacturing — missing link in corporate strategy. Harvard Business Review 1969; 47(3): 136–145

Skinner, CW. The focused factory. Harvard Business Review 1974; 52 (3): 113–121

Hayes, RH, Wheelwright, SC. Restoring Our Competitive Edge: Competing Through Manufacturing. New York: Wiley; 1984

Diaz-Garrido, E, Martin-Pena, ML, Sanchez-Lopez, JM. Competitive priorities in operations Development of an indicator of strategic position. CIRP Journal of Manufacturing Science and Technology 2011; 4(1): 118-125

Nakane, J. Manufacturing Futures Survey in Japan. A Comparative Survey 1983–1986. Systems Science Institute, Waseda University, Tokyo; 1986

Chan, FTS. Performance measurement in a supply chain. The International Journal of Advanced Manufacturing Technology 2003; 21(7): 534-548

Saarijarvi, H, Kuusela, H, Spence, MT. Using the pairwise comparison method to assess competitive priorities within a supply chain. Industrial Marketing Management: The International Journal for Industrial and High-tech firms 2012; 41(): 631-638

Fisher, LM. What is the right supply chain for your product? Harvard Business Review 1997; 75(2): 105-116Lee, HL. Aligning supply chain strategies with product uncertainties. California Management Review 2002; 44(3): 105–120

Impact of Carbon Constraints on Customer Service Levels for an Inventory Model

Sandra van Wijk, Adel Elomri, Shaligram Pokharel, Fatih Mutlu

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

We study a stochastic inventory model operating under carbon emission regulations. The operations are optimized to minimize costs, under a carbon cap policy and a carbon tax policy. For both cases, we derive the impact of the regulations on the customer service level. We show that carbon emission regulations might lead to higher customer service levels, and derive explicit conditions under which this happens in a one customer class model. We illustrate that these observations remain true in a model involving two or more customer classes. Moreover, we show that the service level is not monotonically behaving as function of the carbon cap or the carbon tax value.

Sustainability has become a more important issue for companies over the last few decades. The emission of greenhouse gases (GHGs), and that of carbon dioxide (CO2) in particular, has got a lot of attention lately, as it is seen as a cause of global warming. The most important step to reduce emissions, adopted by many countries, is the commitment to targets on GHG emission reduction as stated in the Kyoto Protocol. Next to externally imposed regulations, companies can also apply voluntarily initiatives to reduce emissions, as that can provide a competitive advantage and demonstrate social responsibility.

Whereas firms traditionally optimize their supply chains with respect to costs and service levels, their focus is now shifting to taking also sustainability considerations into account. This can lead to a change in operational decisions. We focus on inventory management under environmental considerations, in terms of emission regulations. The operational changes a firm makes to adjust for carbon emission regulations can have an impact on the customer service level. The latter is important for a firm, as a high service level leads to satisfied cus- tomers, which might result in increased sales, customer loyalty, and a competitive advantages. While much previous research has focused on the costs versus emission question in inventory models, so far it has remained unclear what the effect of carbon emission regulations is on customer service levels. Therefore, we consider a stochastic inventory model, facing multiple customer classes, where unmet demands are satisfied by emergency supply. We focus on the customer service level: the fraction of demand satisfied directly from stock. The inventory control policy is described by a base-stock level, with rationing level for each class, known as a critical level policy. A demand is only satisfied directly when the on-hand stock level is above a class' critical level. The base-stock and critical levels are optimized to minimize costs given the carbon regulations.

We consider both a carbon cap and a carbon tax policy. In the first case, there exists a cap on the emissions that cannot be exceeded, and in the latter case, a tax is paid per unit of carbon emitted. Carbon emissions are incurred for regular ordering, holding of inventory, and for emergency supply. One might expect that the customer service levels deteriorate when a carbon tax or carbon cap is imposed, but our findings show that carbon emission regulations might also lead

to an improvement in service levels. Hence, the regulations does not always have to be a burden, as might often be thought.

In the one-class model, demand is always satisfied if on-hand inventory is positive, and for a given base-stock level, it is straightforward to derive the average costs and carbon emissions per time unit. From this, the service level can be derived. The only parameter to be optimized in this case is the base stock level, but one needs to resort to enumeration, since there no closed-form expression for the cost (or emission) optimal solution.

We derive explicit conditions, such that the carbon regulations lead the firm to improve its customer service level. These conditions provide a trade-off between the cost and emission parameters for holding of inventory and those for not meeting demand directly from stock (and therefore having to meet it by an emergency supply). There are two opposite effects on the optimal base stock level, and hence service level. Higher holding costs or emissions for emergency supply leads to an increasing service level, whereas an increase in the emission associated with holding or in the costs for emergency supply decrease it.

That is, under a tax policy, the service level is (non-strict):

increasing, if $h/\hat{h} > c/e$;

constant, if $h/\hat{h} = c/e$;

decreasing, if $h/\hat{h} < c/e$;

in the tax level t.

Under a carbon tax, the operations shift from cost optimal to emission optimal, when increases. A carbon cap has the same impact: when the cap gets tighter, the operations again shift from cost optimal (when the cap is large) to emission optimal. Consequently, we do see the same behavior of the service levels. In both scenarios we find either an increase or decrease in service level, however, the scale of the tax level and emission cap on which the changes happen, might differ.

For a two customer class setting, the same kind of behavior of service levels is found. In this case, there is a rationing level R determining whether demand from the lower priority (class 2) customers is satisfied. In the one-class model there was a one-to-one relation between the service level and the base stock-level. In the two-class model, one also has to take the rationing level into account. There are two ways that the service level for a class 1 customer can be improved: a higher base-stock level, and a higher rationing level (more stock is protected for class 1 customers). Class 2 customers will also profit from a larger S, but their service level increases when the rationing level R decreases.

The effect of the carbon regulation on the customer service level is similar to that in the one-class case, however, we now have more scenarios. Both the class 1 and the class 2 service level might either increase or decrease, giving four possibilities, and for suitable parameter choices, we can show that all four do in fact occur.

When holding inventory is relatively low in emissions compared to having to use external supply, the shift to the emission optimal solution will increase the optimal base stock level, which (in itself) increases both service levels. Similarly, a decrease in S decreases both service levels. However, a change in the rationing level might have the opposite effect. An increase in the rationing level provides class 1 with better service at the expense of class 2, and vice verse for a

decrease. However, the effect of combinations of these is not directly clear. Hence the impact of a carbon cap on the service levels is not fully predictable beforehand.

Furthermore, we can show that the service levels do not behave in a monotonic way, when the carbon cap is tightened, or when the tax level is increased. This behavior is a consequence of the behavior of the optimal base stock level S and rationing level R. Where we find R to be decreasing in the carbon cap, the base stock level S might jump up every time R is decreased by one unit, as a function of the carbon cap. As a consequence, the service level might also jump up and down, as a function of the carbon cap or tax.

Our main finding is that emissions regulations like carbon tax and carbon cap can push a firm to increase its service levels, and hence do not always have to be a burden, as one might have expected.

Green Supply Chain Practices in Hungary

Gyöngyi Vörösmarty, Andrea Gelei, Imre Dobos

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

Environmental considerations are getting more and more recognition in literature as the number of publications focusing on green supply chain management is rapidly growing. However publications that have a really complex approach are rare. In our paper we focus on both the purchasing and the distribution side of firms. This makes it possible to get a comprehensive view of the supply chain as a whole and also carry out focused analysis and map specific green techniques related to the supplier and also the customer side of the focal firm. Objective of the study is to develop and present a theoretically well founded on-line questionnaire and using it to give a structured and comprehensive evaluation of green supply chain management techniques of chains active in Hungary. In the questionnaire we focused on the following aspects of greening a supply chain:

1. What are the drivers of greening supply chain processes such as purchasing and distribution?
2. What are the objectives of greening a supply chain? Do purchasing and distribution professionals follow similar or different objectives?
3. What are the specific methods, solutions and techniques applied along the supply chain in order to decrease the negative impact of these processes on the environment?
4. To what extent are inventory related techniques in focus of the greening effort?
5. Do companies measure the effects of different techniques? How?

We also develop a green supply chain index that compresses the above mentioned different aspects. This index and their dimensions make it possible to carry out firm-specific benchmarking in the **field** of greening supply chains internationally, to highlight further development areas and possibilities.

***Keywords**: green supply chain, company practices, index, survey, benchmarking*

***Acknowledgement:** The project is supported by OTKA (K105888)*

Analysis of a Closed-Loop Supply Chain under Name-Your-Own-Price Bidding Mechanism and Capacity Constraint

Xiang Zhu[1], Jianbin Li[2], Qifei Wang[2], Hong Yan[3]

[1] *University of Groningen, Groningen, The Netherlands*
[2] *Huazhong University of Science and Technology, Wuhan, Hubei, China*
[3] *Hong Kong Polytechnic University, Hong Kong*

We study a decentralized closed-loop supply chain consisting of one manufacturer and one retailer. In the reverse channel, product returns are collected under a name-your-own-price bidding mechanism. The manufacturer has a limited capacity to produce new and remanufacturing products. We characterize the optimal pricing decisions in both the decentralized and centralized system and find that the optimal strategies mainly depend on the cost saving of remanufacturing, the potential market size, and the manufacturer's production capacity. By comparison of these two systems, we obtain that the centralized system yields a larger market demand, remanufactures more returns, and can potentially gain more profit than the decentralized system does. Further, we propose a supply contract to achieve channel coordination and a win-win outcome.

Keywords: *decentralized closed-loop supply chain; name-your-own-price; capacity constraint; supply contract; channel coordination*

Service Logistics

Service Engineers Capacity Planning for the Fulfillment of Different Types of Service Level Agreement

Ahmad Al Hanbali, Elisa Alvarez, Matthieu van der Heijden

University of Twente, School of Management and Governance, Enschede, The Netherlands

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

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

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

Sustainable Multi-Echelon Inventory Control with Shipment Consolidation and Volume Dependent Freight Costs

Sven Axsäter, Johan Marklund, Olof Stenius

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

This paper provides exact analysis of a model for sustainable control of a one-warehouse-N-retailer inventory system with time based shipment consolidation. Inventories are reviewed continuously while shipments from the warehouse are consolidated for groups of retailers and dispatched periodically. A key result is the derivation of the probability mass functions for the number of units on each shipment. This allows for realistic volume dependent freight cost structures and emissions to be incorporated in the model. Based on these results, we focus on a particular model setting that emphasizes the model's usefulness from a sustainability perspective. This setting is motivated by industry applications and involves dual options to reserve transportation capacity on an intermodal shuttle train solution, and to use truck transports available on demand. We show how to jointly optimize the reorder levels, shipment intervals and capacity reservation quantities to minimize the total expected costs. Emissions are taken into consideration by use of a side constraint on the total expected emissions or by introducing emissions costs. A numerical example illustrates how the model can be used for evaluating the cost impact of reducing emissions. The analysis is applicable to both single- and multi-item systems.

Keywords: *inventory, multi-echelon, stochastic, shipment consolidation, shipment size, sustainability*

Supplier Risk Quantification: A Case Study

Rommert Dekker, Xishu Liu, Christiaan Heij, Mustafa Hekimoglu

Econometrics, Erasmus University Rotterdam, Rotterdam, The Netherlands

Operators of long field-life systems like airplanes are faced with hazards in the supply of spare parts. Items become obsolete in case the original manufacturers or suppliers end their supply, which may have large impacts on operating costs of firms needing these items. Existing end-of-supply methods are focused mostly on the downstream supply chain, which is of interest mainly to spare part manufacturers. For purchasing firms that have limited information on parts sales, indicators of obsolescence risk can be found in the upstream supply chain. This paper proposes a methodology for firms purchasing spare parts to manage obsolescence risk by utilizing proportional hazard models in terms of supply chain conditions of the parts. The considered risk indicators fall into four main categories, of which two are related to supply (price and lead time) and the other two are related to demand (cycle time and throughput). The methodology is demonstrated using data on about 2,000 spare parts collected from a maintenance repair organization in the aviation industry. Cross-validation results and out-of-sample predictions show good performance of the method to identify spare parts with high end-of-supply risk. Further validation is provided by survey results obtained from the maintenance repair organization, which show strong agreement between the firm's and the model's identification of high-risk spare parts.

Impact of Service Maintenance Planning on Inventory Management

Joeri Poppe[1], Robert N. Boute[1,2], Marc R. Lambrecht[1]

[1] *Research Center for Operations Management, University KU Leuven, Leuven, Belgium*
[2] *Technology & Operations Management Area, Vlerick Business School, Leuven, Belgium*

Many original equipment manufacturers (OEMs) are enhancing their product offering with (aftermarket) services as an important source of revenues and profits. A key element in such a servitisation strategy is the maintenance of the equipment in use (the installed base), which allows them to get hold on the equipment's failures. In our research we focus on the impact of planned (preventive) maintenance interventions on the inventory requirements of spare parts. Using simulation we study the impact of the frequency of the maintenance visits (or inversely, the maintenance interval MI) on the number of interventions and inventory requirements. The study was conducted in close collaboration with an OEM, which enabled us to validate our research approach and findings. We find that the MI that minimises the number of interventions does not necessarily coincide with the MI that minimises inventories. As the cost of interventions often outweighs the cost of inventory, the OEM will most likely focus on minimising the number of interventions, and subsequently adjust its inventory strategy accordingly. Second, counter to intuition, we observe that –even with an increasing failure rate- a higher maintenance frequency may lead to more failures and higher inventories. We also analyse the impact of managing inventories of the planned (preventive) maintenance visits using a proactive (MRP-type) approach vs. a reactive approach (using standard inventory theory) and find that substantial cost savings are possible with the former due to the deterministic nature of preventive maintenance. Finally, we study the impact of performing more or less preventive maintenance during a planned visit on inventories and find that depending on the failure behaviour of the various components, over- or underservicing may be preferred.

Keywords: *maintenance interval, preventive maintenance, inventory, visit frequency, servitisation*

Using Repair Priorities in Systems with Spares and Redundancies

Andrei Sleptchenko[1], Jori Selen[2], Ivo Adan[2], Geert-Jan van Houtum[2]

[1] *Department of Mechanical & Industrial Engineering, College of Engineering, Qatar University, Doha, Qatar*

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

In this paper, we present and analyze using repair priorities of spare parts for a system of parallel machines with redundancies and spare part inventories. When a failure occurs, the failed part is replaced by a spare from stock if possible, otherwise it isbackordered and fulfilled as soon as a ready-for-use part becomes available. The failed parts are at the same time sent into repair and are processed according static priority rules. The analysis of the system availability is based on exact analysis of joint queue length distribution in a three-class single server system. Using the presented models, we show that the repair priorities have a strong effect on the performance of the system. We also show that in many cases static priorities reduce total inventory holding and backordering costs by more than 40%for a fixed system availability.

The Multi-Phase Distribution Problem

Dina Smirnov, Yale T. Herer

Faculty of Industrial Engineering and Management, Technion – Israel Institute of Technology, Haifa, Israel

In the recent decades, there has been widespread interest in Supply Chain Management (SCM). Many companies have realized that managing the supply chain wisely can enhance their profitability and thus help in achieving a competitive advantage. Significant improvement in SCM effectiveness has become possible particularly in the past two decades as a result of rapid communication development. Previously unavailable information regarding inventories at different entities in the supply chain has become available to the decision makers, thus enabling faster and more exact reactions to demand fluctuations.

In many environments, demand of the final customers is uncertain, a fact which contributes to the complexity of SCM. A major tool for coping with demand uncertainty in SCM is inventory pooling. In particular, pooling can be accomplished by additional inventory reviews during the period, a strategy on which we focus in the current research. We consider a system of multiple retailers with a common supplier. Assuming a single production/procurement opportunity per period, we divide each period into multiple sub-periods. At the beginning of each sub-period, part of the available quantity is distributed among the retailers, while the rest is kept undelivered for later distribution. We further refer to this problem as the Multi-Phase Distribution Problem. This constitutes partial inventory pooling which is translated into cost saving. The strategy of additional review can be interpreted as a form of delayed differentiation. When additional reviews are practiced, demand aggregation occurs both in space and in time.

Many researchers have addressed the stochastic problem of one supplier (or warehouse) supplying multiple retailers, and significant progress in understanding such systems has been achieved. However, there still are unsolved issues regarding this problem: some studies did not consider important aspects; some used a set of greatly simplifying assumptions; some performed just an asymptotic analysis, and others obtained their results by simulation due to the complexity of the problem. In other words, although previous research has made a great contribution, generalizing the setting and using analytical tools would be of interest.

We extend the existing work on the additional review topic, by considering a more general setting and by using an analytical approach. In particular, we determine analytically the optimal production and allocation quantities. We also aim to determine analytically the optimal supplementary distribution points in time. We obtained general managerial insights on the system, and we envision increasing its effectiveness.

The Multi-Phase Distribution Problem can be described as follows. Consider a two-stage supply chain, consisting of a single supplier who distributes a single product to multiple independent retailers, each of which sells the product to distinct markets and faces uncertain demand. We focus on a single-period setting, although our setting is directly applicable to a multi-period system in which no stock is transferred from one period to another. Such setting is appropriate for environments in which there is only one production or procurement opportunity before the

beginning of the period. Concrete examples are newspapers and magazines, products with a seasonal demand and products with very long lead times.

Generally, our problem setting is appropriate for any environment in which the supplier is the only one to determine the production and allocation quantities, although the retailers pay the supplier for each item purchased. In some cases, the retailers get a partial or a full refund for the unsold goods.

We apply partial aggregation by dividing the entire period into sub-periods, leaving a certain quantity undistributed at the beginning of the period, and performing a supplementary distribution at the beginning of each sub-period (in the case of more than two sub-periods, there generally will be a quantity left undistributed after each sub period). Such aggregation allows demand fluctuations of certain retailers to be partially compensated by demand fluctuations of other retailers, and thus both holding and shortage costs are saved.

Our research is concerned with situations of identical unit holding and shortage costs across retailers, and zero echelon holding cost. Demand distributions need not necessarily be identical across retailers. Unit shortage cost in all sub-periods is equal. Unmet demand is lost. Shortage cost for lost sales are incurred at the end of each sub-period, but holding cost is incurred only at the end of the last sub-period.

Assuming that the cost of visiting a retailer is zero, the expected cost of such a partially-aggregated system is (weakly) lower than that of a system with the same number of separate retailers. Although the Multi-Phase Distribution Problem has its optimal values of the decision variables, it can achieve the same performance of a completely disaggregated system by using the optimal production quantities of a disaggregated system rather than its own optimal production quantities. Optimizing over the decision variables means that the partially-aggregated system is (weakly) better.

As previously mentioned, our first aim was to determine the optimal initially produced quantity, as well as the quantity distributed to each retailer in each sub-period. Currently, we have obtained analytically the first-order optimality conditions for these quantities for a problem with two identical retailers and two identical sub-periods, and have obtained various insights on the effect of problem parameters on the decision variables. The problem has been previously shown to be jointly convex in the initial decisions, and hence these first-order conditions are sufficient for optimality. Since the optimality conditions are not of a closed-form, we perform a nested bisection procedure on the optimality conditions to find the optimal quantities. Further, we have shown that if certain conditions are satisfied, then the solution to the problem is straightforward, and have found this solution.

The expected cost of the system under consideration can vary depending on the time that the supplementary distribution is performed. Placing the supplementary distribution point wisely can capture much of the benefits of pooling compared to an arbitrary position in time. Literature contains no rigorous analysis on the topic of how to divide the entire period into sub-periods. Our present work in progress is concerned with analytically determining the optimal supplementary distribution position in time, assuming there is only one such point. Intuitively, such point will be found after the middle of the period. To this end, we model demand during the period as a Poisson process.

Along with the previous topics, we explore the case of a non-negligible fixed cost of an additional distribution. Much of the previous redistribution literature assumed that the supplementary

distribution has negligible cost for the supplier. Such is often not the case in practice, as an additional distribution is generally associated with an additional cost. Consequently, it may not be profitable for the supplier to dispatch a truck to retailers whose supplementary quantity is small. We aim to take into account the cost of visiting each retailer in each sub-period, when deciding on the initial production and allocation amounts. Timings of the supplementary distributions must be decided upon a-priori. We model all the above mentioned costs as a fixed cost for visiting a retailer. When including the cost of a visit in the model, the problem becomes more complex, since the decision whether to visit a particular retailer in a particular sub-period depends on the additional quantity to be allocated to this retailer in this sub-period. Of course, this influences the production and initial allocation decisions. To address this problem, a mathematical program was formulated.

Keywords: *additional review, perishable items, risks pooling, single period problem, stochastic planning problem with recourse*

In-Absentia

Multiproduct Batch Production and Truck Shipment Scheduling under Different Shipping Policies

Umit Saglam, Avijit Banerjee, Changhyun Kim

Drexel University, Decision Sciences Department, Philadelphia, PA, United States

This study focuses on a specific supply chain scenario, where a single manufacturing plant produces multiple products for satisfying customer demands that occur at several retail outlets. The production facility can produce only one product at a time, but shipments can be made either directly to each individual retailer via relatively small, less than truckload (LTL) quantities or via larger full truckload (TL) quantities, where deliveries are made to all the retailers according to a peddling arrangement. In the TL transportation mode, a full truckload represents the aggregate retail demand during a common delivery cycle. The required lot sizes are then dropped off at the respective retail locations from the same transport vehicle, which incurs a fixed shipping charge. In the case of LTL shipping, the delivery cycle times for the various products may be different, but any given item has the same inventory cycle time at all retail locations. The shipments are made directly from the supplier to the various retailers individually and the respective shipping costs depend on the amount of load delivered, based on a variable transportation charge. It is to be noted that the production batch sizing issue is represented by the well-known economic lot scheduling problem (ELSP). Our analysis differs from existing work in two important ways. First, we allow inventory depletions at the manufacturing stage to occur in discrete lot sizes. Secondly, we integrate the production plan with either the TL or LTL shipment schedule, as the case may be. In order to keep the computational complexity to a minimum, as well for simplicity of implementation, we adopt the common cycle approach in addressing the production batching issue. The resulting mixed-integer, non-linear programming models (MINLPs) are solved by the BONMIN solver. The results of our numerical experiments show that the respective magnitudes of the key cost parameters play a crucial role in selecting either TL or LTL distribution. When transportation involves no fixed cost, but only a variable shipping charge, the optimal shipment schedule is essentially lot-for-lot with respect to aggregate retail demand. We also observe that under TL distribution, the production and the delivery cycle lengths tend to increase with vehicle capacity. Finally, we outline the parametric conditions under which each of the two transportation policies will be dominant.

Keywords: *TL and LTL shipment policies, integrated production-distribution models*

Inventory Management and Pricing Optimization for Short Life Cycle Products

Ali Cheaitou[1], Christian van Delft[2]

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

[2] *HEC School of Management, Paris (GREGHEC), Jouys-en-Josas Cedex, France*

We develop a single product two-period inventory management and pricing model with backlog, where a retailer orders from a main supplier three amounts of the product at the beginning of the first and second periods, and after the end of the second period. The retailer faces a random demand that is modeled using two independent random variables over a two-period selling season. On the other hand, the main supplier decides on the unit prices to be charged to the retailer for each of these three amounts as well as on the salvage value of the returned quantities. The delivery lead time of the main supplier is assumed to be equal to zero. In addition, a second supply option is available for the retailer, from a distant supplier with a longer lead time, and lower ordering price than the main supplier. Two orders are placed from the second supplier: the first order is place one time-period before the beginning of the first selling period, for a delivery at the beginning of the first selling period; the second order is placed at the beginning of the first selling period, for a delivery at the beginning of the second period. The unit prices of the amounts ordered from the second supplier are supposed to be exogenous to the system and fixed in advance. After the end of the first and second periods, and based on the values of the actual demand, the retailer has the opportunity to return part of the available inventory to the main supplier (or to sell it in a parallel market), at a salvage value fixed by the main supplier. At the end of the first period, any unsatisfied demand is backlogged to be satisfied in the next period. At the end of the planning horizon, any unsatisfied demand is satisfied by using the third order from the main supplier, which can be considered as an emergency procurement order. Using a dynamic programming approach, we exhibit some characteristics of the structure of the optimal ordering policy for the retailer and pricing policy for the main supplier. We provide the structure of the second period optimal policies and some analytical insights concerning the first period optimal policies. Furthermore, through a numerical study, we analyze the effect of some of the model parameters on the optimal policy.

Keywords: *inventory control, pricing, dual supply, supply chain coordination, short life-cycle products*

Exploring the Link Between Inventory and Working Capital Through Variability Reduction Across a Food-Based Consumer Packaged Goods Supply Chain – An Empirical Case-Study

Gina Dumkrieger, Mohan Gopalakrishnan, John Fowler

Department of Supply Chain, Arizona State University, Tempe, Arizona, USA

Recently, a global recession and tight credit markets have created a challenging environment for businesses in many of industries. Most recently, the uncertainties regarding the timing and type of economic recovery have added to the pressure. Hence, firms have been relentlessly focused on managing their working capital in a prudent manner. It is widely acknowledged that effective supply chain management practices can reduce operating costs and logistics expenses, significantly impacting a company's working capital.

One such practice is identifying and managing variability across the supply chain, since increasing variability will degrade supply chain performance. In any given system it is clear that if the throughput rate (or equivalently the same average exogenous arrival rate) is fixed, by Little's Law, the average inventory (mostly, work-in-process, WIP) in the SC increases if the cycle time increases. Cycle time could increase due to inefficiencies in the system such as "change-over" time variability in manufacturing plants. However, if constant changes are made to the arrival rate (say to factories) due to variability created by forecast errors, then it has even more drastic effect on the WIP and hence the working capital.

In this study, based on data from a real-world company that manufactures and distributes packaged food we explore examining the variability across the supply chain (supplier-manufacturing-distribution). Specifically, we undertook the following steps:

a) Map the value chain and identify the variability drivers and collect information about the drivers

b) Correlate the relationship between the drivers and performance (example safety stock) through Pareto analysis

c) Analyze the impact of short-term buffers (inventory, capacity and lead-time) on performance for given level of variability, including potential target values

d) Identify ways to reduce variability

Our approach included data mining on forecasting, orders placed and shipment data. We also analyzed downtime and changeover data at the manufacturing plant level and developed a "travelling-salesman" based approach to optimizing the sequence dependent setups. Lastly, we analyzed the outbound shipments to recommend centralization of inventory between the plant, regional distribution center and other customer-facing distribution centers.

Keywords: *variability reduction, forecast accuracy, changeovers, centralization*

Optimal Inventory and Capacity Decisions with Lateral Transhipments

Ki-sung Hong[1], In-Chan Choi[2], Ilkyeong Moon[3], Chulung Lee[1,2]

[1] *Graduate School of Management of Technology, Korea University, Seoul, Republic of Korea*
[2] *School of Industrial Management Engineering, Korea University, Seoul, Republic of Korea*
[3] *Department of Industrial Engineering, Seoul National University, Seoul, Republic of Korea*

We consider centrally controlled multi-location inventory systems which coordinate their inventory policies using lateral transhipments. Lateral transhipments are movements of products between locations at the same echelon. Each location has pre-determined inventory capacity and stochastic demand for a single product. However, capacity at each location could be expanded with additional variable cost. The problem is to determine the inventory capacity, replenishment quantity at each location and how much to tranship between locations. The planning horizon is finite and unsatisfied demands are lost. We consider replenishment, transhipment, inventory holding, capacity expansion and penalty costs at each location and develop a mathematical model to obtain the optimal capacity, the optimal inventory replenishment quantity and the optimal transhipment quantity at each location to minimize the total cost. The optimality properties are obtained. Using the optimality properties, we develop an efficient algorithm to obtain the optimal values of inventory capacity, replenishment quantity and transhipment at each location. In order to examine the effect of the transhipment cost and the penalty cost on the optimal solutions, we conduct extensive numerical experiments and illustrate the results by graphical means. The numerical results show that the replenishment quantity is increasing in the transportation cost and the penalty cost, and the transhipment quantity is increasing in the penalty cost and decreasing in the transportation cost.

Keywords: *multi-location inventory system, inventory control, capacity decision, lateral transhipments, centralized decision*

Capacitated Lot Sizing Problem for Inventory Optimization with Uncertain Seasonal Demand: A Case Study

Lorena Polo Navarro[1], Carmen Galé Pola[2]

[1] *Aragon Institute of Technology, Zaragoza, Spain*

[2] *Universidad de Zaragoza, Zaragoza, Spain*

Production lot-sizing has a great impact on inventory, particularly under seasonal fluctuations of demand and constrained production capacity. Some companies maintain high levels of inventory to face periods of uncertain seasonal demand. A production schedule which does not adjust accurately the real demand may lead to overstocks for some products and stock-outs for other.

The aim of this paper is to develop a mathematical model to compute the optimal inventory mix to face stochastic demand at minimum cost in periods of high demand. We focus on a new variant of the single-level multi-product dynamic lot-sizing problem under stochastic demand subject to capacity and service level constraints. In this problem, a schedule of production orders is determined over the planning horizon in order to minimize the inventory holding costs. The model takes into account considerations such as service level required, production capacity at machine level, warehouse capacity, set up time or product-machine allocation. The integration of stochastic demand in the production/inventory model is performed through the statistical distribution of the forecast accuracy.

The applicability of the proposed model is illustrated empirically using a real case study: a fast-moving consumer goods company which manufactures pet products for different retailers in Europe. The demand for this kind of products mainly concentrates in Christmas time and the capacity of the manufacturing processes is limited, so they must launch the production orders months before, being the forecasting and planning process a very time-consuming task for the managers of the company. As a result, the inventory grows, they require off-site storage facilities and the global holding costs increase. Despite this, demand is not always met for some products, whereas for other, excessive amounts of inventory remain after the Christmas period.

The methodology proposed in this paper has provided the company with a tool to improve the processes of forecasting, production scheduling and inventory optimization in an integrated way. In fact, it has been implemented in a computer program used by the company as a decision support system. The first results obtained show inventory reductions of more than 10% and significant improvements in the planning process time.

Keywords: *inventory, optimization, lot-sizing, forecasting, case study*

Inventory Routing Problem with Time Windows (IRPTW) for Deteriorating Items

Gede Agus Widyadana[1], Takashi Irohara[2]

[1] *Department of Industrial Engineering, Petra Christian University, Surabaya, Indonesia*

[2] *Department of Information and Communication Sciences, Sophia University, Tokyo, Japan*

Inventory routing problem (IRP) has been discussed by many researchers due to the importance of this problem. In recent supply chain management, many suppliers try to reduce their inventories by letting vendor to control their inventory. Suppliers have benefit by reducing their inventory cost, since the inventory cost still be paid by the vendor. In the other side, the vendor has benefit by reducing inventory and delivery costs. The vendor can schedule their delivery and control their inventory to reduce the costs.

There are few researchers focus on inventory routing problem for deteriorating item, however many items such foods, electronic deteriorate in time. Some products also have perishable characteristic. Time windows constraint is suitable to be used in deteriorating and perishable items, since time constraints is one of the important factors to get fresh items on time. From our intensive literature review, few papers discuss inventory routing problem for deteriorating items. So we will develop an inventory routing problem with time windows for deteriorating items. We assume that delivery time is deterministic, only one product is considered, there are more than one vehicle and each vehicle only has one tour for every replenishment time. In our model, we also assume that each vehicle has similar maximum capacity and deteriorating rate during delivery and storage are different.

This model has two constraints that have to be considered, which are vehicles capacity and time windows. These two constraints effect to complexity if the model. Due to complexity of the model, Particle Swarm Optimization (PSO) is used to solve the problem since PSO can solve problems in reasonable time with near optimal solution. A Numerical example are provided to illustrate the theory. Key parameters changes that affect costs are shown in the sensitivity analysis. From the results of the numerical example and sensitivity analysis, some interesting results are found.

Keywords: *inventory, IRP, time windows, deteriorating items, PSO*

Stackelberg Model for Two Echelon Deteriorating Inventory with Unreliable Machine

I. Gede Agus Widyadana[1], I. Nyoman Sutapa[2], Jani Rahardjo[1]

[1] *Industrial Engineering Department, Petra Christian University, Indonesia*

[2] *Business Management School, Petra Christian University, Indonesia*

In reality it is difficult to get good a reliable machine and it result in higher cost. In this model we develop two echelon deteriorating inventory model where manufacture has an unreliable machine. The machine can not be used at the scheduled time since it should be maintained or used by other product. Manufacture has ability to produce products in a fixed production rate and deliver the products to the retailer. Since machine is not reliable, some products can not be delivered in the right time and result in lost sales for the retailer. As a consequence, the retailer has to buy in a big lot. This decision result in higher inventory cost for retailer and give profit to the manufacture. Retailer decide a fixed ordering quantity and ask manufacture to send them in more than one time delivery. The optimal condition is occurred if manufacture and the retailer make collaboration to minimize the supply chain cost. However in reality, it is difficult for them to make collaboration decision since they want to optimize their own benefit. When manufacture and retailer have equal bargaining power, then they will try to optimize their own profit so the Stackelberg game model will occur. In this model we try to develop a Stackelberg game model between manufacture and the retailer for deteriorating items and unreliable machine. We use some assumptions such as production rate is bigger than demand rate, there is no breakdown machine during production period, demand rate and production rate are constant, deteriorating rate is constant and deteriorating items can not be fixed. Manufacture has decisions to set his selling price and stock out compensation. In the other side, the retailer can make decisions about quantity of item each delivery and number of delivery in one replenishment period. The model is a NP-hard model, so we use Genetic Algorithm to solve the model. A numerical example is used to show how the model works and a sensitivity analysis is employed to show the relevant factors of the model to optimize the decisions. The results show some interesting relations of manufacture and retailer decisions.

Keywords: *inventory, two echelon, unreliable machine, deteriorating items, Stackelberg Game*

Optimizing a Warehouse Network for Non-Blood Inventories in Blood Collection Operations

Eunae Yoo[1], Brock Oswald[2], Mohan Gopalakrishnan[1], John Fowler[1]

[1] *Department of Supply Chain Management, W. P. Carey School of Business, Arizona, State University, Tempe, AZ, USA*

[2] *Deloitte LLP, Chicago, IL, USA*

Humanitarian logistics is charged with organizing the cost-efficient and effective storage and distribution of goods to meet the demands of those in need. One branch of humanitarian logistics is the management of blood collections in which the coordination of non-blood inventories, such as medical equipment, is critical. Without these items, blood collection would be impossible. In this paper, we empirically studied the American Red Cross (ARC)'s warehouse network that supports its Biomedical Division, which is responsible for blood collections. The warehouses restock non-blood inventories based on a min-max level system and push product to ship-to-locations depending on expected blood collections.

Our objective was to evaluate current and potential ARC warehouse locations and cost parameters to design a warehouse network that minimized total annual operating and transportation costs. To accomplish this, we adopted a linear fixed charge model and held constant transportation and holding costs per unit. Additionally, we incorporated demand for non-blood inventories. Due to the large number of such items, we created a hypothetical unit called the "donor pack." The donor pack consisted of all non-blood inventories required to collect, process, test, and distribute a single collection of blood to the end recipient. For each expected blood collection supplied by a warehouse, we associated a demand of one donor pack.

We used these inputs to optimally select warehouse locations from across the U.S. Since the number of potential and current warehouse placements was substantial, we decomposed the U.S. into five regions (e.g., northeast) and categorized the warehouses as belonging to 1 of 5 regions. We then ran regional optimization models with regional demands. The selected warehouses in the regional models were aggregated to an overall model, which formed an optimized warehouse network and distributed donor pack demand. Based on demand allocation of donor packs, we calculated how much of each non-blood inventory needed to be stored at each warehouse.

The model's results indicated that ARC should shut down 7 of its existing warehouses and construct 2 new warehouses. This would result in a total cost savings of 23 percent. All in all, our model enabled us to address two important strategic issues for humanitarian logistics: determining (1) warehouse locations and (2) the placement and quantities of prepositioned supplies.

Keywords: *humanitarian logistics, blood collections, fixed-charge model*

Authors' Index