Book of Abstracts

20th International
Symposium on Inventories

August 20-24, 2018
Budapest, Hungary

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August 20-24, 2018 - Budapest, Hungary

ISBN 978-615-5270-46-8

Editor-in-chief: Attila Chikán
Technical editor: Robert Hohol (Diamond Congress Ltd.)

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

Printed in Hungary - 2018
OOK-Press Ltd., Veszprém, Hungary
Responsible for printing: Attila Szathmáry

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Plenary Lectures

Cross-country Production-inventory Optimization with VMI+JIT Coordination – An IBM Case Based Study

Zhixiang Chen

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Objective of study: The objective of his paper is to investigate the decision of production-inventory for cross-county supply chain, illustrating how the VMI and JIT can effectively be combined together to form an effective inventory control system to reduce cost and improve the global supply chain inventory management.

Materials and methods: This study is motivated from the examination of empirical data of IBM Asian Purchasing Operation Center in Shenzhou, China. The company implemented VMI system for the component inventory between PCBA in Shenzhou and IBM assembly in USA, and a JIT purchasing policy of PCB parts for the PCBA factory in Shenzhou. This paper is trying to model the decision of this cross-country supply chain inventory with VMI+JIT coordination mechanism, illustrating the optimal strategies of cost saving and inventory control for IBM.

We established the decision model of the production-inventory with VMI+JIT, transportation modes and supplier payment scheme are major considered factors in the decision models. Meanwhile, centralized and decentralized decision models are developed and compared.

Results: Via the decision models, we obtain the optimal purchasing and transportation model combinatory strategies, implications for saving cost and inventory control for IBM Asian Purchasing Operation Center are given based on the model analysis.

Conclusions: The model can be extended to consider more other factors, e.g., time-varying demand and multiple risks of supply.

Keywords: *Production-inventory; cross-country supply chain; transportation*

Controlling Inventories in Omni-channel Distribution Systems with Variable Customer Order Sizes

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Omni-channel distribution systems brings new challenges for efficient inventory control. One such challenge concerns service differentiation across channels when upstream central warehouses satisfy both direct customer demand, and replenishment orders from downstream retailers. In traditional one-warehouse-multiple-retailer (OWMR) inventory systems, where the warehouse only replenish downstream retailers, research has shown that it is optimal with a relatively low service level at the central warehouse. This is typically not a viable solution in an omni-channel system where end customers ordering directly from the warehouse also expect high availability of products.

We consider this problem in the context of a continuous review OWMR model, with direct customer demand at the warehouse and (R,Q) policies at all inventory locations. The motivation for our work stems from industry collaboration and real data characterized by highly variable customer order sizes and service level constraints. Service differentiation at the warehouse is achieved by reserving some stock for the direct customer demand. We model this by introducing a base-stock controlled virtual retailer at the warehouse with a replenishment lead-time of zero if the warehouse has stock on hand. The base-stock level S is interpreted as a reservation level at the warehouse. Similar approaches have previously been successfully used for backorder cost models in the literature. In these models, an attractive feature is that methods for traditional OWMR systems can be applied directly to evaluate and optimize the system. In our settings with fillrate constraints and highly variable customer order sizes, this is no longer the case; direct application of such methods can lead to poor solutions.

We analyze this problem and develop computationally efficient approximation methods for determining the reservation level at the warehouse, and the reorder levels at all stock points. A numerical study, including real data from two different companies, illustrate that the proposed methods perform well. The solutions are close to target fill-rates and offer significant opportunities to reduce total inventory costs compared to existing methods.

Keywords: *omni-channel, inventory, multi-echelon, stochastic, service level*

Industrial Symbiosis Networks

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An industrial Symbiosis Network (ISN) consists of companies that are producing residue products (or waste), next to their primary output, and companies that can use these residue products as feedstock for their own production processes. In this way, both the disposal of waste to nature and the use of fresh natural resources is reduced, hence ISN's essentially contribute to a more circular economy. Such networks should be sustainable not only from an ecological but also from an economic and societal perspective. In this presentation we introduce a framework to characterize various Industrial Symbiosis Networks and discuss various informational aspects. Next, we turn to the operationalization of one particular Industrial Symbiotic relationship, and show how (i.e. under what circumstances) mutually acceptable pricing schemes can be achieved. We use an agent -based simulation approach to validate our approach and discuss an application in practice.

The Future of Supply Chains

Mike Wilson

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Supply chains are changing - for decades we have lived with the elongated, take-make-dispose supply chain, whereby production is centralised in low-labour cost countries and finished goods are shipped throughout the World. Globalisation, ease of communication, International Trade Agreements and outsourced operations to specialised organisations helped supply chains to develop, thrive, mature and commoditise. We invested in reducing inventory with sophisticated forecasting and modelling techniques, sought to reduce lead-times, increased transparency and efficiencies in supply networks, but we kept the overall model the same. The trends we are now experiencing is challenging that model. As consumers, we want products personalised and we want them now...we have an 'expectancy of immediacy' fuelled by e-commerce where speed to market becomes critical. We are seeing inventory increase to cope with instantaneous demand as we expedite the elongated supply chain. We have technological advances in manufacturing with additive techniques, robotics and artificial intelligence that allows production to be distributed, product to be personalised and manufactured closer to consumption and we dispense with economic batch and order quantities. We are embracing product as a service, the shared, subscription and loop economy that promotes a circular supply chain. Overarching all of this we have a marco-economic and political swing towards National Protectionism that threatens Globalisation. All of these factors promote the fundamental question...are we in need of a new supply chain model

What Prevents the Application of Inventory Theory in Practice?

Sean P. Willems

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I apologize in advance for the informal nature of this abstract. A journal submission would be more rigorous but given the 2500-character limit I need to be efficient. I am not sure if this is best suited for the special topic on empirical inventory or not.

I have had the good fortune to see the application of inventory optimization as both an academic and practitioner. I develop inventory optimization models, primarily based on the guaranteed service model for inventory optimization, and I co-founded a software company Optiant (later acquired by Logility).

This year I am part of the Intel team that is a finalist for the INFORMS Edelman award. The work documents the ten-year journey Intel has undertaken to fully automate inventory target setting. In brief, more than 99.5% of their inventory targets are automatically accepted without any planner intervention on a weekly planning basis; the system manages more than one billion dollars of inventory at all times. This is the first system I know of that is fully automated requiring no planner intervention. A few years ago I was an Edelman finalist with P&G and even though that deployment encompassed hundreds of planners there was still manual approval required by planners.

I have given talks on this work at major practitioner-focused supply chain conferences and our top academic conferences. When practitioners learn the Intel implementation took ten years they literally cannot believe it was so fast. When academics learn the Intel implementation took ten years they are incredulous it took so long.

I have come to clearly understand why inventory optimization is hard to implement in practice. First, is forecast bias. Bias is much harder to eliminate in practice than academics think. Second, is correctly mapping the product supersession process. New products are constantly replacing older products and this consumes an enormous amount of planner time. Third, a planner's objective function is quite different than minimizing expected cost. A planner wants to optimize availability subject to a budget constraint; this will often require stocking much more than our academic models would predict.

My talk will draw on many real-world implementations where I can share before and after data, make clear what academic assumptions needed modification, and present several cases where practitioners would not implement our academic models. I will define the important dimensions many academic models are missing.

Keywords: *forecast bias, forecasting, inventory optimization, theory versus practice*

Economics of Inventories

Analysis of Inventory and Pricing Decisions of a Differentiated Duopoly Supply Chain with Power Dynamics and Gray Markets

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Managing gray markets has become a challenging and important task for managers. In practice, premium brands from developed countries are very popular all over the world and premium brand manufacturers are often multinational companies that not only focus on developed countries but also open business in developing countries. On the contrary, due to the low level of R&D capability, local brand manufacturers in developing countries seldom enter the market of developed countries due to the fierce competition. Other factors, such as production costs, political barriers, and particular certificates may also cause a manufacturer to sell the products in just one market. Once the premium brand manufacturers enter the lowdemand market (i.e., the market of developing countries with the low willingness to pay), the gray market emerges as a big challenge to the premium brand manufacturer when a third party finds opportunities for arbitrage to import the products from developing countries to developed countries.

Our paper is motivated by this practice in the pharmaceutical industry (Acharyya and García-Alonso 2012). The innovator pharmaceutical firm located in the developed countries is often the patent-holder multinational corporation that sells new drugs not only in developed countries but also in developing countries. The firm in the developing countries only has the technology to produce an inferior product and is unable to improve on the quality produced by the innovator firm. Therefore, the firm in the developing countries can operate only in the local market and can't enter the developed countries due to the inferior quality of the drugs. Arbitrage then causes the presence of the gray markets, and the pharmaceutical products made by the innovator firm are subject to parallel imports. In this situation, the innovator firm is more likely to move at first and the local firm in the developing country is the follower as the imitator. There is another example for the emergence of gray markets with the manufacturer competition only in the low-demand market. In the dental implant market, the premium brand manufacturers in North America and Europe produce high-quality dental implant products and sell their products not only in developed countries but also in developing countries. While there are some manufacturers in East Asia, they produce relatively low-quality products with a low price. Due to strict certificates and consumer preference, it is very difficult for these Asian manufacturers to enter North American and European market. In this circumstance, manufacturer competition exists in the low market (i.e., East Asia), while the premium brand manufacturer monopolizes the high market (i.e., North America and Europe). Gray market emerges as a big challenge to the premium brand manufacturer when third-party parallel importers import the

products from East Asia to North America or Europe. In this situation, the premium brand manufacturer may move at first and the local manufacturer in Asian countries follows. Alternatively, the premium brand manufacturer and the manufacturer may act simultaneously (Taleizadeh et al. 2017).

Motivated by the above situations, this paper studies the gray-market issues and characterize the optimal inventory and pricing decisions in a differentiated duopoly where various strategic interactions occur between manufacturers. The main contributions of this paper are as follows. First, we study the gray market issues in a differentiated duopoly in the low-demand market. We present a model that captures two salient features in the practice, i.e., the asymmetry between manufacturers and power dynamics. To the best of our knowledge, these features have not been studied in the extant literature related to gray markets and thus provide a novel and important dimension to this paper. Second, this paper shows that the conclusion in Shavandi et al. (2015) that parallel importation can increase the leading manufacturer's profit does not hold. The leading manufacturer should take measures to prevent the presence of gray markets. Third, we extend our model to study and compare two different leadership structures (i.e., DMS with MN) under the gray market setting. It is easier for the gray markets to emerge under MN because the emergence of gray markets under DMS requires a great demand difference between markets. Both manufacturers are more prone to engage in "Dominant Manufacturer Stackelberg" when the parallel imports or the products of the following manufacturer are competitive. The parallel importer may prefer the "Manufacturer Nash game". Finally, our analysis show that the following manufacturer benefits from an increase in the discounted value of parallel imports and the parallel importer benefits from an increase in the quality of the following manufacturer's products. The following manufacturer increases the sale quantity and the price of its products as the demand in the high market increases. Thus, the following manufacturer's profit operating only in the low market becomes higher as the demand in the high market increases.

Housing Stock Construction, Remodeling and Demolition in Growing and Shrinking Cities

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This paper examines the drivers, outcomes and modelling of European demographic ageing, population decline and shrinking cities in their functional regions, considering possible impacts on housing stock and housing stock management. Evidence from OECD and European Union reports, should motivate discussions about the likely long-run effects of demographic change on the housing stock. Until now there has been relatively very little analytical interest in these demography-related issues facing many cities (McCann, 2017). Since recently, there did not appear to be a single paper which aims to track the links analytically between population decline, population ageing, housing stock and the long-run financial viability of the city (Carbonaro et al., 2016). One of the first such papers have been presented at ISIR and published in IJPE (Bogataj et al., 2016). As it is highlighted in the paper of McCann, all of the ongoing efforts in developing model-based analytical frameworks in urban economics are focused on growing cities and construction of new buildings. McCann argue that the lack of any formal analysis of housing stock in shrinking cities also regarding the long-run financial positions of cities may well be related to the fact that the field is dominated by North American issues, and as he highlighted, North America is a continent facing ongoing national and urban population growth. But his remark is wrong. Typical example of shrinking city is Detroit. In the coming years, the trends of city dynamics in EU will continue, shaped by differential patterns of migration, ageing of population and related housing inventory management. But the impacts of these dynamics will not only depend on the population profiles but also on the social infrastructure on the city, regional and national level. Here local taxation policy and EU funds would need to contribute to smart decline or growth of housing stock and related social infrastructure. How to support the decisions on investments in housing and design the social infrastructure, including social insurance funds as the insurance mechanism which enables transfers of purchasing power from younger to older cities and towns, and housing equity withdrawal is subject of this presentation.

Keywords: *Shrinking cities, housing stock, social infrastructure, multistate transition model*

Inventory Impacts of Current Global Processes

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The first decade of the 21st century brought substantial changes in some of the processes influencing inventories at the company and national economy level alike. In a recently published book* the authors analysed the macroeconomic factors of inventory investment in developed economies between 1970 and 2013. Current trends seem to deviate from those in effect in the previuos decades. We study in particular two main tendencies:

- the impacts of protectionist tendencies and other disturbances in global trade processes
- the consequences of penetration of use of new IT techoloqies in business.

Statistical analysis of the same countries as in the referred group prepares the ground for providing explanation based on surveying opinions of business analysts.

**Chikán et al (2018): Inventories in National Economies, Springer*

Multi-player Model Analysis of Carbon Emission Reduction in China's Steel Industry

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During past decades, consequence of carbon dioxide emissions has become a common concern worldwide. China's steel industry faces with problems such as extensive pattern of production mode and serious pollution. The carbon emission trading mechanism as a market means has been used to optimize allocation of resources and reduce carbon emissions. How to motivate companies to comply with carbon emission constraint set by government in the framework of the carbon emissions trading mechanism is a concerned issue.

This paper builds a multi-player model to study companies' environmental behavior in maximizing their profits under carbon caps applicable to China's steel industry, in which a carbon emission trading mechanism is implemented. An analytical solution to the optimal policy for multi-player in the industry is developed. The study selects three major steel-making companies in China to carry out case example analysis in the context of carbon emissions trading mechanisms. The results show that companies' carbon emission coefficient, carbon emission reduction investment, initial carbon emission quota, and carbon emission trading price have their impacts on the optimal policy for multi-player in the industry. The implications from the study indicate that a smooth carbon emissions trading needs both government and companies to actively participate in, the government plays its important role in governing policy and regulating carbon emissions trading system. The companies in the industry need to have a long-term strategy to take part in the carbon emission trading process.

***Keywords**: Carbon caps, Carbon emission trading, Production optimization, Multi-player model*

Newsvendor Problem under an Endogenous End-of-Season Demand

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The newsvendor (NV) problem assumes that the salvage/clearance price at which the leftover inventory is disposed of is a given parameter of the problem. In this paper, we relax this assumption and consider the NV problem with the salvage/clearance price as a decision variable. We have drawn from the literatures on the NV problem and clearance/markdown/dynamic pricing to develop three stochastic models in this paper. Our NV model differs from the extant clearance pricing models in three ways. First, while the clearance pricing models consider multiple periods for discount sale, our model considers two distinct periods – normal season and end-of-season. Second, while clearance pricing models may allow multiple replenishments during discount sale, our model allows a single replenishment opportunity only at the beginning of the normal season. Finally, while most of the clearance pricing models take the initial order quantity as a given parameter and the clearance prices in different periods as decision variables, our model considers both the initial order quantity and the prices in the normal season and end-of-season as decision variables. Our model is different from the clearance pricing models, and is also more general and practical in the sense that a NV faces a short selling season followed by a short end-of-season to clear his stock where his primary concerns are how many or how much to order before the start of the normal season and what prices to charge both in the normal season and in the end-of-season so as to maximize his profits/revenues. In the first model we have developed, we assume that while the seasonal demand is exogenous and stochastic, the end-of-season demand is endogenous and deterministic. The second model extends the first model by assuming that the end-of-season demand is endogenous and stochastic. Finally, the third model considers that both the seasonal and end-of-season demands are endogenous and stochastic. We have provided solution procedures for solving the stochastic optimization problems. We have also performed sensitivity analyses to assess the sensitivity of the optimal expected profit and order quantity to different problem parameters. Specifically, we have found that the optimal expected profit is most sensitive to the variable cost per unit, mean seasonal demand and market potential of end-of-season demand. Our models will be useful for retailers of products with a short selling season and a short end-of-season period for clearance sale of leftover inventory such that there is a single replenishment opportunity at the beginning of the season and a single opportunity for setting the salvage price for clearance sale based on the leftover inventory and end-of-season demand pattern. The paper is concluded with possible directions for future research.

Keywords: *Newsvendor problem, Endogenous end-of-season demand, Stochastic optimization*

Optimizing Pricing and Ordering Decisions of Firms in Presence of Piracy

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In this paper, a selling problem in a competitive market is considered where two manufacturers sell their substitutable products through its traditional retail channel to customer. In addition, one of the manufacturers uses an online direct channel to sell its product, in addition to its traditional one. According to the assumptions, the manufacturers presents their items in a competitive market where the items are substitutable and the customers can buy their desired items from manufacturers. Each manufacturer proposes incentive contracts, revenue sharing and profit sharing contracts, to the retailers to establish a win-win situation for the chain members, and achieve the maximum supply chain profit.

The most important issue in this article is considering the possibility of piracy. Here, supposed that there is the possibility of piracy a product from the traditional and online direct channels. The model is developed under different game theory methods which are Nash, Stackelberg and collaborative methods to implement the optimal pricing and ordering strategies. Also, in a numerical example, we examine the validity of the relationships obtained and the impact of piracy on the problem decision variables and the profit of each of the chain members.

***Keywords**: Pricing, Ordering, Dual Selling Channel, Competitive Market, Game Theory*

The Impact of Tax Legislation on Inventory and Supplier Selection Models

Hua Jin, Patrick Beullens

Operational Research (OR) provides the methods and techniques by which firms can maximise their profits by taking smart decisions. The OR literature in the area of logistics, however, pays scant attention to cash flows that arise in order for the firm to fulfil its legal obligations. This paper develops a methodology for constructing models that explicitly account for the impact of tax legislation on a series of classic inventory management problems. It does this by expressing the future profits of the firm after tax as the Net Present Value or Annuity Stream Value of the cash flow function associated with the activity for the firm, including these cash flows exchanged with relevant third parties and the government that are needed in the context of ensuring compliance with tax legislation. Using the legislation in the United Kingdom (before Brexit), the research established how the explicit consideration of Value Added Tax (VAT) scheme, Corporate Tax (CT) and import duties and tariffs rules affect optimal decisions for a firm with respect to the optimal associated product ordering policies. We examine the implications from European Union legislation on acquisitions as well as international based import on inventory management. We find that tax rates as well as tax schemes that apply to the firm are important in particular for products with lower profit margins. Taxes not only affect the optimal inventory policy, but may also influence the sourcing and supplier selection strategy.

Keyword: *EOQ, NPV, UK Tax*

Forecasting for Inventories

A New Fill-rate Based Performance Evaluation of Forecasting Methods for Optimal Spare Parts Management

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In the area of forecasting-based spare parts management, accurate selection of the forecasting method is primordial. To address this question, the academic literature provides a plethora of investigations, whereby a forecasting method is linked to a particular review system for which, it provides estimates of the related replenishment quantities. Afterwards, performance measurements are accomplished and used for inventory decision making and also, for evaluating relative performances of forecasting methods. Indeed, much of the literature since the 1990s emphasizes the necessity to compare forecasting methods by assaying the effect of their use within a service level (fill rate and/or cycle service level) oriented inventory control system (e.g. Teunter and Duncan, 2009 and Syntetos et al., 2015). It should be noted, however, that though the widespread use of the *CSL* criterion, it is the least advocated for determining optimal replenishment quantities since it does not offer a clear picture of the customer service (Axsäter, 2006). Substantially, the fill-rate *(FR)*, given by the fraction of demands that may immediately be fulfilled from available stock on hand, is viewed more convenient to be used. However, seldom are the studies occurring to the *FR* criterion because of its property in adding complexity to the inventory model. Yet, commonly observed mixed-findings on the relative forecasting methods performances along with under-stocking issues, given by the *CSL*-based studies, heightened our interest in conveying performances under the *FR* criterion. In this paper, we fill a gap in the literature by conducting an empirically based comparative study where the performance of two bootstrapping methods and a parametric forecasting method in determining the optimal replenishment quantity under a target FR constraint, is tested using of the traditional definition of the *FR* appeared in Brown (1959). Several important results can be emphasized. First, the existing forecasting methods are adapted to the *FR*-based performance criterion. Second, tradeoffs between existing *Csl*-based and *FR*-based criteria show that using the latter constraint yields higher service performances and avails lesser underachievement cases of the target services. Finally, we put evidence on the effectiveness of the bootstrapping procedures for high target *FRs* and lumpy demand patterns, while the parametric forecasting method outperforms for moderately intermittent data.

Keywords: *intermittent demand, fill-rate criterion, order-up-to-level, forecasting, bootstrapping*

A study of Different Croston-like Forecasting Methods

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An often-adopted technique for short-term forecasting is the single exponential smoothing (*SES*); it is available in most computer systems for material- and production control. With help from it, it is possible to continually update reorder points for an efficient inventory control. But the ability for SES to forecast an item when the forecasting time periods often have zero demand, slow moving items or intermittent demands, is questioned. Croston presented an idea and method to separate ordinary exponential smoothing in to two parts; the time between demand (or withdrawals), and demand size. The forecasts are then updated only when there is a demand. Since then modifications of Croston's idea have been suggested and also an idea to measure the fraction of periods with zero demand compared to non-zero demand. Four different suggestions to treat intermittent demand are tested. The different techniques are compared with Mean Squared Error *(MSE*), Cumulated Forecast Error (*CFE*) and with the bias measure "Periods in Stock" (*PIS*). Our tests show that *Croston*'s original idea may be to prefer; some techniques overestimate and others underestimate demand in certain circumstances.

Levén and Segerstedt (2004) presented a modification of Croston's idea (*ModCr*). Every time there is a demand a new experienced demand rate is calculated. The update occurs when there is a demand, but maximum is once per time unit, which will be day. If there are several demands during a day, the demands are added together. The demand rate is the quotient between the demand and the inter-demand interval:

$$If\ X_t = 0, \text{ then } \hat{d}_{t+1} = \hat{d}_t \tag{1}$$

$$If\ X_t \neq 0, \text{ then } \hat{d}_{t+1} = \hat{d}_t + \alpha\left(\frac{X_n}{t_n - t_{n-1}} - \hat{d}_t\right). \tag{2}$$

Levén and Segerstedt (2004) write: "The way we modify Croston's method avoids the bias Syntetos and Boylan have found (although we were not aware of their paper from the beginning)." We meant naturally the alleged bias in the derivation of *Croston*; not that *ModCr* never should show bias. Boylan and Syntetos (2007) interpret it falsely and write: "Levén and Segerstedt (2004) claimed that the MC estimator avoids bias but, as shown below, this is not the case." Teunter and Sani (2009) continue: "Levén and Segerstedt (2004) further proposed a method that they claimed to be unbiased (abbreviated as LS), but their method is even more biased as we also show in Section 3."!? - What is bias and what is not bias; is mostly not entirely clear and requires proper

analysis and discussion; it will be further treated in this paper. *ModCr*, except Levén and Segerstedt (2004), has shown unsatisfactory results with overestimation of demand (Boylan and Syntetos (2007), Teunter and Sani (2009), Wallström and Segerstedt (2010)). This study does not recommend *ModCr* or modifications of it, instead stay to original *Croston*. - Reading forecasting literature it is easy to get the opinion that everything, every item in an inventory should be forecasted; but that is not necessary. A complementary solution in many cases could be not to stock the item, only buy it on demand. Our study shows that original *Croston* does not have more dangerous bias than the modification of Croston from Syntetos and Boylan (2001).

Keywords: *Forecasting, Inventory control, Intermittent demand, Croston, Exponential smoothing*

An Approach to Inventory Planning Based on Simulation and Performance Trade-off Curves

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Conventional logic in inventory management takes most decisions, such as inventory policy or capacity constraints, as given and the planner has focus on setting the appropriate inventory levels, given forecasts and their uncertainty, to meet the predefined service levels. Furthermore, operational decisions, such as the choice of forecasting method, are not directly connected with inventory performance, but rather rely on convenient proxies, such as forecast accuracy.

Although these choices permit simplification of the inventory management that is beneficial both for making the problem analytically tractable, but also practically implementable, it can also lead to inefficiencies. We argue that each "fixed decision" forces constraints in finding the optimal inventory management setup that may not allow reaching the minimum cost solution. To this end, we propose an inventory management framework that casts the various decisions in terms of inventory performance metrics and therefore allows us to consider them simultaneously in a multi-objective optimisation setting. We investigate the effect of relaxing some of these constraints on the final inventory decisions. Effectively, we explore the possibility and the potential of blending decisions that are typically considered as tactical or strategic with the operational ones, reaching a multi-level optimal plan. We identify examples where modern supply chains can accommodate such blending and evaluate the effects of the proposed multi-objective optimisation framework in contrast to the conventional thinking, that can be seen as locally optimal, but globally suboptimal planning process.

An Empirical Evaluation of Prediction Intervals

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While a lot of attention has been devoted to the evaluation of the point forecasts of different forecasting methods and approaches (see for example the Makridakis competitions), the empirical evaluation of prediction intervals has not attracted equal attention. This problem becomes even more important if one considers that the prediction intervals produced for a forecast model could be potentially used directly to inform inventory-related decisions, such as setting the safety stock levels.

While there are theoretically sound methods of prediction intervals construction, the simpler approximations are often used in practice. We propose comparing several existing techniques for prediction intervals construction (namely parametric, semi-parametric, nonparametric, as well as widely-used approximations) in order to explore which of them is more robust and in which circumstances each of the methods performs the best.

Our evaluation considers a variety of:

- forecasting methods (exponential smoothing, ARIMA, etc),
- forecasting horizons (reflecting to short versus long-term decisions),
- data frequencies (yearly, quarterly, monthly), and
- confidence levels (80%, 90%, 95%, …).

Our empirical evaluation uses the 3,003 series of the M3-competition that has been extensively used for forecasting evaluation purposes. Moreover, the evaluation of the prediction intervals is performed in terms of:

- coverage, i.e. the percentage of the real values that actually fall within the prediction intervals.
- upper coverage, which directly reflects to the achieved customer service level,
- spread, which can be associated with the inventory held, and
- mean interval score (MIS), that simultaneously takes into account the coverage and the spread of the prediction intervals.

Our results from the evaluation of the prediction intervals are contrasted with the performance of the point forecasts (mean estimate) of the various methods.

Keywords: *Forecasting, prediction intervals, evaluation, inventory*

Estimation of Discrete Cumulative Distributions by Resampling

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Slow-moving demand is highly discrete and does not always conform to standard probability distributions. For such items, the cumulative distribution function (CDF), which is required for stockcontrol purposes, is difficult to estimate. Non-parametric approaches have been suggested in the literature, including non-overlapping blocks aggregation, overlapping blocks aggregation, and resampling with replacement - also described as (non-parametric) bootstrapping. The last approach has been adopted in commercial software and has been used, with some adaptations, by a wide range of companies in North America.

In this paper, we analyse some of the properties of the resampling with replacement approach as an estimator of the cumulative distribution function. Our contributions are as follows:

1. We show that this estimator is biased and give a general expression for the bias.
2. For a forecasting horizon of two periods, we show that the bias is always in the interval [-1/4n, 1/4n], where n is the length of demand history, and identify the conditions under which the maximum bias is attained.
3. We give a general expression for the variance of the CDF estimates, and evaluate specific expressions for horizons of two and three periods.
4. We compare the variance of the CDF estimates obtained from resampling with replacement with resampling without replacement.

We conclude by comparing the stock-control implications of the two resampling approaches with overlapping blocks aggregation.

Forecasting - Inventory Control: Mind the Gap

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The majority of contributions in inventory theory assume that demand (and its parameters) are either deterministic or known. The explicit recognition that demand is actually unknown and thus needs to be estimated is an important step towards more realistic theoretical developments, but still not particularly helpful unless forecasts are somehow accounted for. Even then, most often than not, forecasts are treated as an exogenous variable that feeds into a stock control model. This is also the case with many software packages which themselves overlook potential interactions between forecasting and inventory control. Finally, there is a stream of inventory control research that is explicitly built around forecasting uncertainty.

In this paper we are concerned with the interaction and integration (or lack of) between demand forecasting and inventory control. We conduct a structured review of relevant academic contributions in the area of inventory control, and argue for their classification in regard to forecasting integration, from disregarding to exploiting the interactions: i) demand is considered deterministic, or assumed to be known; ii) need to forecast demand is merely mentioned; iii) forecasting is an (exogenous) input to inventory control; iv) forecasting and inventory control are fully integrated. We show that the development from one level to another is in many cases chronological in order, but also associated with specific schools of thought. We also argue that although movement from one level to another adds realism, it also adds complexity in terms of actual implementations, and thus a trade-off needs to be established. The article makes a contribution into an area that has always been fragmented despite the importance of bringing the forecasting and inventory communities together to solve problems of common interest. We close with an indicative agenda for further research and a call for more theoretical contributions but also more work that would help to expand the empirical knowledge base in this area.

Forecasting and Inventory Control with Compound Poisson Demand using Periodic Demand Data

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Objectives of study: Although compound Poisson demand is a popular choice in inventory control literature and practice, there exists hardly any guidance for obtaining its parameters from real demand data. Forecasting literature and software are focused on predicting period or lead time demand, which does not yield consistent estimates for the parameters of a compound Poisson distribution. Consistent alternatives from the statistics literature have severe biases in finite samples. We propose a new, intuitive, consistent, closed-form method of moments estimator and study its performance in terms of estimation accuracy and inventory control performance

Materials and methods: The new method separates estimating the arrival rate (using the fraction of periods without demand) and estimating the mean of an individual demand size (using the estimated arrival rate and the mean of period demand). We compare its estimation accuracy to that of Croston's method, the standard method of moments estimator, and the maximum likelihood estimator, for geometric and exponential compounding distributions. Furthermore, we compare the order levels and achieved fill rates in a base stock inventory model with compound Poisson demand.

Results: The new method is consistent and outperforms the standard method of moments approach if there are at least some periods without demand. Croston's method has an asymptotic bias in both the arrival rate and the demand size mean. Also the maximum likelihood estimator, which can only be obtained using a numerical search, has a larger finite-sample bias. Croston's method sets order levels consistently too high. Although all other methods lead to order levels and fill rates that converge to their targets, the new method dominates in convergence speed.

Conclusions: The new method yields inventory reductions, avoids fill rate overshoots, and thus achieves cost savings, while reducing computational complexity. If the demand pattern shows at least some intermittency, then the new method performs best. The performance difference increases in the level of intermittency of demand.

Keywords: *Demand Forecasting, Inventory Control, Compound Poisson, Intermittent Demand, Service Levels*

Future Manufacturing Quantity Prediction Method for Low Cost Global Cooperative Manufacturing

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Manufacturing industry is required to change from "local manufacturing for local demand" to "global cooperative manufacturing" due to rapid market change and unstable world affairs. Many companies have expanded their business by "local manufacturing for local demand". However, overtime work and facility utilization down have occurred due to imbalance between production capacity and demand, so manufacturing cost is high. Therefore, they will change to "global cooperative manufacturing". In this manufacturing, future manufacturing quantity prediction is important because production order allocation is executed according to the prediction. We have developed future manufacturing quantity prediction method realizing high prediction accuracy.

One of current methods uses order information. The method consists of four steps. Firstly, order specifications are selected based on correlation with lead time (LT) from order receiving to production completion. Order specifications include product type, delivery region and so on. Secondly, LT mean value are calculated from similar past orders which are searched based on the specifications. Thirdly, production due date for each order is calculated from the LT mean value. Finally, future manufacturing quantity is calculated from the date.

However, prediction accuracy is low when it is applied to order-made products like elevator and storage. This is because it uses mean value. Mean value is effective when distribution of samples is normal distribution and the number of them is large. However, in order-made products, LT distribution of similar past orders is non normal distribution and the number of them is small. Hence, mean value is not effective.

To cope with non normal distribution and small samples, developed method has two features. Firstly, the method uses probability distribution instead of mean value. It can represent non normal distribution by calculating frequency of samples. Secondly, the method derives LT probability distribution considering multiple specifications by combining those of each specification by Bayesian Inference. This enables to use many past orders.

We verified prediction accuracy with data of elevator and storage. We confirmed accuracy was improved by 28% in elevator and by 15% in storage. In future, the method will use economic indicator for further high accuracy.

Keywords: *Global cooperative manufacturing, Future prediction, Order-made product, Probability distribution, Bayesian inference*

Optimising Forecasting Models for Inventory Planning

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Inaccurate forecasts can be costly for the operations of companies, in terms of stock-outs and lost sales, or over-stocking while not meeting service level targets. The forecasting literature, often disjoined from the needs of the forecast users, has focused on providing optimal models in terms of likelihood and various accuracy metrics. However, there is evidence that this does not always lead to better inventory performance, as often the translation between forecast errors and inventory results is not linear. In this study, we consider an approach to forecasting model parametrisation by directly considering appropriate inventory metrics and the current inventory policy. We propose a way to linearise the competing multiple inventory objectives, i.e. meeting demand, while eliminating excessive stock, and use the resulting composite objective function to identify inventory optimal parameters for forecasting models. We evaluate the proposed parametrisation against established alternatives and demonstrate its performance on simulated and real data. Furthermore, we explore the connection between forecast accuracy and inventory performance and discuss the extent to which one is an appropriate proxy of the other.

Problems and Modelling Methods in Inventory Research: Mapping the Intellectual Structure through Text Mining

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This study attempts to depict the intellectual structure of inventory research and propose a model to extract the problem topics and the corresponding topics for solution/modelling methods. Firstly, we identify the topics as well as the evolution of topics in inventory research between 1975 and 2018. Then we propose to conduct problem-solution pairing by identifying the development of research issues along the past decades of literature in inventory research, and the corresponding modelling methods in this field. More specifically, we aim to summarize research questions and methods by analyzing the data structure consisting of question and method words. Then we establish the relationship between problem and method topics in a language modeling framework. We use text mining technology for realized the research objective due to the significant amounts of documents involved in the above mentioned publication period. Finally, based on the understanding of the problem-solution relationship, we suggest potential new research directions in the field, both from research problems perspective and modelling methods aspect.

Keywords: *Intellectual Structure, Inventory Research, Problem-Solution Pairing, Topic Modelling*

Using Demand Uncertainty as a Determinant of the Bullwhip Effect

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The Bullwhip Effect is a common problem for many supply chains, characterised by an upstream amplification of demand variability, which results in various costs being incurred. The Bullwhip has been widely researched, investigating potential causes to possible remedies. Nevertheless, a key issue lies in quantification of the problem itself. Currently, the metric adopted by most of the papers, consists of taking the ratio of variance of demands between the upper and lower echelons at the original demand frequency, to determine whether the Bullwhip exists and its magnitude. This metric measures the propagation of the variability of demand. We argue that demand uncertainty, rather than variability, should be gauged as a determinant of the Bullwhip. Since poor demand forecasting is one of the original causes of the phenomenon and is also a cost driver for the ensuing decisions made across the supply chain, it should be examined as an indicator for the Bullwhip. First, we discuss the limitations of the current metric, before proceeding to devise a new metric that captures the propagation of uncertainty. We then inspect different scenarios where the two metrics are compared in terms of cost performance, highlighting the strengths and shortcomings of each metric, as well as exploring what implications each metric has for potential managerial actions to manage the Bullwhip Effect.

Inventory Management

Components Inventory Control in an Assemble-to-Order System with Rush Ordering

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In the automotive industry, the first tier suppliers should maintain a high service level (close to 100%) towards the original equipment manufacturer (OEM). A large part of suppliers are thus located near to the OEM and work in synchronous delivery. We study the case of a first tier supplier which assembles car seats. This supplier uses an assemble-to-order (ATO) setting that consists of multiple finished goods (FGs) and multiple components. We propose an approximate model to calculate the optimal components safety stocks in an ATO system with the option of using rush ordering (i.e., receiving an emergency shipment) in case of potential component stock-out.

In our model, we assume that component inventory is controlled using a (T,S) order up-to level policy. Customer orders for each FG are assumed to arrive according to an independent Poisson process. For each component, a firm order is sent to supplier each time interval T and is received after a constant delivery lead time. This order is indeed received in multiple shipments instead of receiving the full order in a single shipment. The assembly capacity is assumed to be sufficient to satisfy customer demand. In case of component stock-out, suppliers offer the possibility of using rush ordering with a fixed unit cost. We assume that rush orders have a negligible lead time. We propose approximate expressions of optimal components safety stocks which minimize the sum of inventory holding and rush ordering costs. We show that finding a close form expression of optimal components safety stocks is complex due to interrelationships among demand, regular delivery ((T,S) policy), and rush delivery.

The approximate model of optimal safety stock calculation is compared to the exact model (the exact model is implemented using discrete event simulation) over a large set of scenarios. The comparison shows that the approximate model is efficient. Then, a sensitivity analysis on relevant system parameters such as unit rush ordering cost, component average demand and assembly coefficient is conducted. The proposed model is applied to the case of a car seats maker plant and shows interesting cost reductions compared to the currently used inventory calculation model.

Keywords: *inventory control; assemble-to-order, rush ordering; periodic review; optimization*

Data Driven Inventory Control using Stochastic Optimization

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We reconsider the classical single-item newsvendor model with service level restrictions. We study data-driven approaches that base the inventory decision directly on the historical observations for demand and related variables (such as Google search data or weather data), instead of specifying an intermediate demand forecast. We show that a straightforward, normality-based data-driven approach achieves below target service levels, and suggest improvements. Moreover, we propose and test three new approaches that make different distributional assumptions. We further extend our results to the multi-item case.

Different Channel and Product Preferences in a Supply Chain of Internet and Traditional Channels

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In almost every product category sold on the Internet, consumers have the option of buying from traditional retailers instead. This study considers pricing policies in a duopolistic market consisting of an internet and a traditional retailer. Retailer offers a conventional version of the product, and an internet direct channel offers an organic version of the product directly to the consumers. Consumers perceived the organic version offered by the internet as healthier and environmental friendly. On the other hand, a traditional retailer offers the consumer better service and a "personal touch" shopping experience than the direct channel. Under the assumption that consumers are heterogeneous with respect to their willingness to pay for these two attributes, a unique two-dimensional vertical- differentiation consumer choice model is developed.

Several questions are addressed: First, how do the value of the attributes affect the parties pricing? Specifically under what conditions the common practice that the direct internet price is lower than the retail price hold. Second, which party benefits from increasing the attributes' value and how does it affect the consumer. Finally, because the market may not be fully covered in relatively young industries, how does the equilibrium pricing differ for covered and non-covered markets?

Surprisingly, although E-commerce has low overhead expenses and communication costs, the internet's price can be higher than that of the traditional retailer. This market configuration occurs only when the market is fully covered, the value of the attribute offered by the internet channel is higher than the value of traditional retailer attribute and the retailer's extra cost is smaller than this positive gap between the attributes values.

Furthermore, we found that all consumers buy one of the product at equilibrium regardless of their valuations, when the value of the attribute of the internet (organic) is higher than the value of the attribute of the traditional retailer (service). Moreover, we identify the maximal purchasing cost for which this result holds, once the value of the attribute of the traditional retailer is higher than that of the internet channel.

Keywords: *internet channel; retail channel; channel conflict; Pricing; game theory; vertical differentiation; two-dimensional*

Disposal versus Rework - Inventory Control in a Production System with Random Yield

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In a production environment where random yield plays a fairly significant role, a decision has to be made on how to handle products that do not satisfy given quality requirements. We consider a single-stage production system with a positive production time and random yield. To ensure that only high quality items are sold to the customer, a post-production quality control system has been put in place. We compare two different strategies for defective items: disposal or rework. Disposal is possible without any time delay whereas the rework process requires a positive rework time. While disposed-of items leave the production process, reworked products stay in the process and are assumed to be as good as products that are perfect when they are initially produced. The end products are stored in a warehouse to satisfy stochastic demand. We show how to determine the optimal base-stock level, which is very difficult because of unknown covariances between orders. Subsequently, an optimization model is proposed to support the planner's decision on which strategy to choose when it comes to whether to dispose of or rework defective items. By means of a sensitivity analysis we show which parameters directly affect this decision and give managerial insights. The analysis indicates that significant cost reductions can be obtained by choosing the best strategy for defective products.

Dual Sourcing and Smoothing under Non-Stationary Demand Time Series: Re-shoring with SpeedFactories

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We investigate the emerging trend of near-shoring a small part of the global production back to local SpeedFactories. The short lead time of the responsive SpeedFactory reduces the risk of making large volumes in advance, yet it does not involve a complete re-shoring of demand. Using a breakeven analysis we investigate the lead time, demand, and cost characteristics that make dual sourcing with a SpeedFactory desirable compared to off-shoring to a single supplier. We propose order rules that extend the celebrated inventory optimal order-up-to replenishment policy to settings where capacity costs exist and demonstrate their excel- lent performance. We highlight the significant impact of autocorrelated and non-stationary demand series, which are prevalent in practice yet challenging to analyze, on the economic benefit of re-shoring. Method- ologically, we adopt Z–transforms and present an exact analysis of several discrete-time linear inventory models.

Keywords: *dual sourcing, order smoothing, auto-regressive demand, integrated moving average demand, global outsourcing*

Dynamic Shipments of Inventories in Shared Warehouse and Transportation Networks

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There is significant recent interest from researchers and practitioners to employ shared warehouse and transportation networks for increased consolidation of freight transport. In addition, technology is available for real-time tracking of inventory levels at warehouses and items in transit. These trends enable dynamic shipments of inventory between warehouses in the network depending on the most recent inventory information. Effectiveness of dynamic shipments will generally depend on the available connections. Therefore, this paper focuses on the relation between network structures and optimal inventory control decisions with dynamic shipments. We propose a novel modeling framework for dynamic shipments of products through networks in discrete time under discrete stochastic demand, which generalizes various well-known inventory models from the literature. This framework is applied to situations with a company participating in a shared warehouse and transportation network. Optimal solutions are obtained using Markov decision processes. Different network structures with four warehouses are compared with each other in a full-factorial experiment, where product characteristics such as demand variability, stock-out behavior, and cost parameters are varied. Our results indicate that product characteristics significantly influence the effectiveness of different network structures. In situations with high shipment costs, effectiveness of networks depends mostly on the distances of warehouses from the main warehouse. However, with lower shipment costs, the number of available edges between warehouses become the driving factor, especially when there is a combination of backordering and highly variable demand. In such situations, traditional two-echelon-like network structures can be least effective of all possible network structures. In our experiments, the average costs per period can be reduced considerably by using dynamic shipments over static shipments, between 10% and 20% in typical instances.

Keywords: *shared warehouse and transportation network; dynamic shipments; network comparisons; inventory; markov decision process*

Inventory Model for Perishable Drugs with Fixed Shelf Life under Stochastic Demand Condition

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Hospital drugs have strict requirements in shelf life and service level. Misusing expiring drugs or drug shortage will have a serious impact on patients and harm the pharmaceutical industry. Therefore, reasonable inventory management of perishable drugs can not only reduce losses caused by drug expiring or shortage, but also be helpful for patients' treatment. In this paper, by considering fixed shelf life, emergency ordering costs and outdating costs, we present an inventory model of perishable drugs under stochastic demand condition, while the probability of a perished product remaining in stock is accounted of. Based on the proposed model, we analyze the influence of stochastic demand and shelf life on the ordering cycle and the optimal ordering quantity of drugs. Then the optimal ordering cycle and quantity decisions that minimize the total costs are drawn out. Numerical and sensitivity analysis verify the feasibility of the proposed model for drug inventory management. Conclusion and insights for management are provided accordingly.

Keywords: *stochastic demand, perishable drugs, inventory model, shelf life*

Inventory Policy under Distribution Free Demand in the Dual-Channel

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A dual-channel inventory model is proposed in this paper, in which stocks are stored in the warehouse of both manufacturer (upper echelon) and retailer (lower echelon), and the product is accessible in two supply channels, i.e. a conventional retail store and an online channel, taking on a rapid development. In the presence of stockout in one channel, customers shall search and be transited to the other channel with a known probability. The two sides encounters with both horizontal and vertical competitions. Six demand scenarios are analyzed in this paper in the case of customer being switched between two channels. On that basis, the inventory model of the manufacturer and the retailer is built, and the optimal inventory policies are attained for the unknown demand distribution. Eventually, sensitive analysis is carried out to ascertain the customer switching rate, production cost, wholesale price, sale price and shortage cost.

Keywords: *customer, switching dual-channel distribution, inventory policy*

Inventory Position Management

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This paper researches position management, which is a term for an applied technique in commodity industries for managing both the physical and the financial positions of inventory volume changes. The focus of the paper is aimed at the explanation of inventory position management principles by comparing multiple commodity industries (e.g. coal, oil, steel, cereals).

The reasons for inventory volume changes are mostly described by physical necessities (e.g. demand seasonality; supply chain disruptions, especially at long-haul supply-demand differences; commodity processing capacity maintenance cycles), and as a consequence the related price risk mitigation actions are triggered – while active position management focuses not only on the related price risk management, but it can also have an impact on the physical side: assumptions based on the forward market structure might imply inventory build-up or draw-down decisions, through which additional value can be created.

After examining the relevant literature review, the paper attempts to structure the position mangement phenomenon in commodity industries, while also tries to generalize the key concepts identified. Live cases, industrial examples, related supply chain dilemmas are discussed.

Stock-piling decisions are analyzed both on short-term (intra-month) and mid-term (6-18 months), up to the point where there is liquidity in the commodity derivative market. Once positions are taken, a constant re-evaluation is recommended in order to accomodate the actual positions to the market circumstances, again both on physical and financial sides.

The findings are presented as a combination of theory and empirical results. Inductive approach is applied in the research by observing the phenomenon and analyzing data, after which the results are compared in various industries, in order to formulate and support the hypothesis of the value creating characteristic of active position management.

Keywords: *position management, stock-piling, price risk, commodities*

Investigating the Cost-benefits of Labelling Postponement – A Simulation Case Study

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Volatility of demand, increasing product diversity and shortened product life cycles require for fast and flexible strategies to cope with these uncertainties. Postponement strategy describes the delay of product differentiation until customer orders are received or future product demands are anticipated. Motivated by the case of an international manufacturer of consumer goods with frequent product relaunches, the objective of this study is to develop a multi-period, multi-product decision model for partial postponement. With this model, we study a group of products that can be configured into country-specific variants which only vary in the applied labels. Due to high volatility of regional product demands, large safety stocks are required. On the other hand, excess inventories lead to obsolete products in the course of product packaging relaunches.

Although it has been shown that postponement can lead to benefits such as inventory cost reductions, postponement is also accompanied by postponement costs as for example costs for additional handling. Therefore, the cost-benefits of postponement decisions have to be studied under the present product- and processspecific conditions.

Based on a case study, we develop a discrete-event simulation with the software AnyLogic to analyse postponement strategies in comparison with make-to-stock (MTS) strategies under various parameter settings and scenarios. In this model, we consider the production planning, manufacturing processes, and the warehouse operations, using historical product demand patterns to account for demand variability.

The results of the simulation experiments show how different operational parameters, such as the demand forecast accuracy and frequency of product relaunches affect the decision for postponement or MTS. For the studied case, it is indicated that the postponement strategy results in a reduction of inventory holding costs and direct production costs by eliminating the product labelling bottleneck in the production line. However, it also becomes evident that the advantageousness of postponement strongly depends on the demand, process characteristics and assumed postponement cost estimates.

In conclusion, it can be shown that postponement offers a viable strategy to reduce inventories when product demands are variable and frequent product relaunches occur. However, the trade-off between postponement related costs and postponement benefits has to be investigated thoroughly.

Keywords: *postponement, make-to-stock, discrete-event simulation, customer order decoupling point, inventory control*

Joint Replenishment of Multiple Retailers in Inventory Management with Carbon Caps

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Today, retailers are not only facing great pressure to reduce operational costs to gain competitive advantage, but also under increasing pressure to reduce carbon emissions. While it has been shown in many studies that joint replenishment generally brings cost savings, it is not clear how it will affect the total amount of carbon emissions of the participating retailers and what kind of coalition structures will be formed if joint replenishment does not always reduce the total amount of carbon emissions. These are the questions that we attempt to address in this paper.

More specifically, in this paper we consider the joint replenishment problem among multiple retailers subject to carbon caps. We first develop a model of the joint replenishment problem with a carbon cap and identify the optimal joint ordering policy for this problem. Then, we establish a carbon emission game for the joint replenishment problem with carbon caps in the framework of the cooperative game theory. The carbon emission game is shown not to satisfy subadditivity in general. Therefore, we propose an algorithm to generate a coalition structure which is shown to be optimal for the carbon emission game. That is, this generated coalition structure minimizes the total amount of carbon emissions for all the retailers involved.

Keywords: *joint replenishment; carbon cap, cooperative game theory, nonsubadditivity, coalition structure*

Acknowledgement: *The authors acknowledge the support of National Natural Science Foundation of China (No. 71531003 and No. 71432004), Research Grants Council of Hong Kong (No. T32-102/14N), and the Leading Talent Program of Guangdong Province (No. 2016LJ06D703).*

Jointly Optimal Buyer-supplier Contracts via Third Party Coordination

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In an ideal world, cooperative and jointly optimal lot-sizing decisions would be an obvious practice. Supply chain partners would cooperate closely and freely share information to reach optimality. Additional profit gained from this cooperation would be fairly split between the two parties. Unfortunately, we do not live in an ideal world. Typically, there exist numerous obstacles preventing a cooperative and jointly optimal outcome. The common solution proposed in the literature is the use of adversarial and non-cooperative coordination mechanisms (e.g. quantity discounts), resulting in suboptimal lot-sizing decisions and a possible loss of good will. There is, however, no need to give up the optimality of a joint decision, nor the spirit of cooperation, if we address the relevant issues through a different and possibly more effective approach. Previous work in this context has proposed and explored some benefits and repercussions of adding an external third-party coordinator (3PC) to a traditional buyer-supplier coordination effort for designing purchasing contracts. While few would consider this solution a panacea, the substantive potential gain of attempting to achieve a supply chain optimal outcome motivates us to explore this option more fully. In particular, we consider a rational, profit-seeking 3PC, which is wary of committing resources to assist a coordination effort that is likely to yield potentially negligible or even negative returns on investment. This paper contributes to the literature by offering an optimization procedure utilizing a third party, which plays a key role in obtaining the cooperation of both the buyer and the supplier. Our analysis includes many cost components not typically factored in supply chain decisions, e.g. the buyer's and the supplier's respective opportunity costs of commitment to a contract. Furthermore, we consider the feasibility and the necessary conditions for a profit-seeking external agent, i.e. a third-party coordinator, in possession of limited information at the outset, to be interested in assisting such a contract coordination effort. We demonstrate the benefit of our approach via a series of numerical experiments and sensitivity analyses.

***Keywords**: supply chain, buyer-supplier contracts, commitment risk costs*

Life Time Extension and an Application to PC Upgrading

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In the field of maintenance, a lot of literature consider the physical deterioration of capital asset, e.g. using the Weibull distribution to model the deterioration process. However, in some cases physical deterioration is not the key reason for maintenance. For example, a PC customer wants to replace the CPU not because of its breakdown but the launch of a new version of CPU with higher performance. Comparing with physical deterioration we call it commercial deterioration.

We consider asset life time extension based on commercial deterioration which aims to increase the economic life of asset. The trade-off is between replacing the asset completely and conducting a partial upgrade. We build a Markov decision model to obtain the upgrading policy which has a positive impact on life time extension.

This presentation combines the PC case with the Markov decision model. We apply our model to the PC case including upgrading the CPU, GPU and HDD. We fit the curve of commercial deterioration of CPU, GPU and HDD with hand collected dataset. Based on the commercial deterioration, we obtain the performance level above which life time extension policy leads to upgrading the component instead of replacing a PC.

***Keywords**: life time extension, commercial deterioration, component upgrading, maintenance, Markov decision process*

Moving to Additive Manufacturing for Spare Parts Supply

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We investigated when and how a transition to additive manufacturing (AM) becomes profitable for the low-volume spare parts business. Our study is motivated by a case study conducted at an OEM of radar system who foresees various opportunities that become available with the transition to AM. In particular, it is the case company that can perceive the prospects of shortened lead times and the promise of tool-less manufacturing. Yet, the skepticism remains whether a transition will pay off amid high AM production costs and uncertain AM technology advancements. We use stochastic dynamic programming to assess the situation encountered at the company. Therefore, we regard particularities such as decreasing AM production costs over the course of the service horizon and determine if (and when) AM should be prepared or tooling be discarded. We substantiate our results using numerical experiments which allow the evaluation of more general conditions.

For the case company, an immediate investment in AM technology is the best strategy and enables more than 15% cost savings. Furthermore, the results of the numerical experiments show that lead time reductions, high inventory, and backorder costs often promote early investment in AM technology, despite (initially) higher AM production costs and additional setup costs. Also, we find that postponing the investment in AM is often not advisable. Instead, conventional manufacturing and AM should be used parallelly before a complete transition to AM becomes profitable. The value of AM for spare parts supply appears to be underestimated. Company-specific business cases may convince management about the value of moving to AM technology for spare parts supply but require closer collaboration between industry and academia.

Keywords: *digital manufacturing, 3D printing, maintenance, defense industry, stochastic dynamic programming*

Multi-period Policies for Dynamic Inventory Rationing

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In distribution firms, customer orders can be characterised by different priorities. Various contracts with different unit price or lead times or order quantities are offered to customers, indeed. For instance, in the automotive spare part industry, orders can be issued to repair a vehicle off the road (VOR) or can be issued by dealers (DO) to replenish their own inventory. The VOR orders require consistently short lead time, while for DOs long lead times are acceptable. Thus, VOR orders have higher priority than DOs. In such cases, strategies can be implemented to allocate on-hand inventory among orders with different priorities (namely, *inventory rationing strategies*). Usually, a critical level is set such that, when the on-hand inventory falls below it, low priority orders are not served any more, while keeping parts for future high priority orders.

Keywords: *Inventory Rationing, inventory management, supply chain, Multi-Period policies, Multiple Demand classes*

Net Present Value Approach of a Newsvendor Problem with Delay Payment

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This paper considers a newsvendor problem, consisting of a retailer and a wholesaler that take into account the timings of events, and the opportunity costs of independent firms. The objective of this model is to determine the optimal order quantity, in order to maximize the expected total profit. The comparison between the proposed model and the traditional newsvendor model, the effect of variability of demand, opportunity costs, and delay payment are discussed. Numerical analysis is used to illustrate the implementation of the solutions and the degree to which parameters system affected decision making and the expected profit. The results show that the retailer is always better off using NPV model instead of traditional newsvendor problem and vice-versa for the wholesaler. We also conclude that when involving delay payment, the benefit gain increase for both parties when the demand is highly variable, and the retailer's opportunity cost is larger than the wholesaler's opportunity cost.

Keywords: *net present value, newsvendor, delay payment, inventory model, credit term*

On a Method to Improve Your Service BOMs within Spare Parts Management

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In industries where the uptime of equipment is highly important, such as the semiconductor industry, customers have service level contracts with the Original Equipment Manufacturer (OEM). These contracts specify the aggregate time a machine can be down due to spare parts. Companies operate service networks to support these logistic contracts. To determine spare parts stock levels they need to forecast spare parts demand. An important input for this forecast is the service Bill Of Material (BOM), which specifies the applicable spare parts for a machine. Each machine installed in the field has its own service BOM.

The service BOM is usually derived from the machine configuration. The initial configuration (as-built) is similar to the manufacturing BOM, but may change over time due to modificative maintenance or machine upgrades resulting in a current configuration (as-maintained). Because of a growing installed base, increasing machine complexity, and an increasing number of product variants, companies face a challenge in defining and maintaining these configurations, which is why the service BOM is not always in line with the actual machine.

A missing part in the service BOM of a machine results in a forecast which is too low and can lead to too little stock to meet the service level agreements from the service contracts. This is called understock. The opposite, overstocking, might occur when a part occurs in the service BOM, but does not occur in the machine. These effects are amplified when such a mismatch holds for a whole group of machines.

In this paper we study the service BOMs at a large OEM in the semiconductor industry. We investigate the possible root causes for mismatches between the service BOM and the actual configurations of machines, and we develop a method to generate alerts for possible mismatches. This method builds on multiple sources of configuration information: the service BOM, the configuration (as-maintained), the engineering BoM, engineering procedures, and the machine's historical spare parts usage. Each alert can be studied in further detail by employees who are responsible for the different types of configuration data. These employees can assess whether there is a real mismatch, and, if so, they can fix the mismatch. Our method was tested in a pilot study, and found to be very useful.

Keywords: *configuration management, spare parts, inventory management, forecasting, data science*

On the Empirical Performance of TOPSIS for ABC Inventory Classification

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ABC classification is widely used by companies to deal with inventories consisting of very large numbers of distinct stock keeping units. Single-criterion ABC classification methods are often used in practice and recently multi-criteria methods have attracted the attention of academics and practitioners. Several models of multiple criteria decision making (MCDM) have been developed to deal with the multi-criteria ABC inventory classification (MCIC). Most of these proposed models emphasize on developing the inventory items classification process, comparing the ranking results with other models and a very little research consider the inventory performance of such models. Moreover, very few MCIC models have been empirically analyzed based on a combined cost-service inventory efficiency and to the best of our knowledge, there is no research that has investigated the efficiency of the technique for order preference by similarity to ideal solution (TOPSIS). TOPSIS represents one of the most known and commonly considered MCDM models. Therefore, the objective of this study is to empirically investigate the cost-service inventory efficiency of the TOPSIS model and some of its variations. The performance of these models is also compared to some mathematical programming-based MCIC models. This study is conducted through using a dataset of 47 SKUs which has been commonly used in the literature and a real large dataset that consists of 9086 SKUs obtained from a retailer located in Netherlands that sells do-it-yourself products. The results enable insights to be gained into the comparative performance of TOPSIS and MCIC models.

Keywords: *ABC inventory classification, multiple criteria decision making, TOPSIS, empirical investigation*

Optimal Lateral Transshipment Policies for a Two Location Inventory Problem with Multiple Demand Classes

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Downtime of machines is an expensive cost factor for many companies. This especially holds for technically advanced machines that are used in the primary processes of their users. Examples include trucks for a transportation company, medical equipment in hospitals, and machines in a production line of manufacturing facilities. To reduce down times, and hence loss of revenue, ready-for-use spare parts are kept on stock at locations close to these machines, to be able to quickly respond to a breakdown. Spare parts, however, can be extremely expensive, while demand rates are low. Moreover, downtime cost of systems might differ, and hence demands differ in importance, resulting in a system with multiple demand classes.

In order to reduce costs, we allow for stock transfers between the local warehouses, so-called *lateral transshipments*. Case studies in literature have shown that cost reduction up till 50% are possible by the use of lateral transshipments, but that the use of it might also lead to increasing costs. The question is, when costs can be saved.

To study this, we consider a multi-location, multi-class inventory system, providing repairable spare parts for a critical component of advanced technical systems. We are interested in the optimal lateral transshipment policy. There are three ways in which a demand can by satisfied: from own stock, via a lateral transshipment, or via an emergency procedure.

Using stochastic dynamic programming, we characterize and prove the structure of the optimal policy for a two-location system, that is, the policy for satisfying the demands which minimizes the average operating costs of the system. This optimal policy is a threshold type policy, with state-dependent thresholds at each stockpoint for every demand class. We show a partial ordering in these thresholds in the demand classes. In addition, we derive conditions under which simple, easy to implement, policies are always optimal. These policies are the so-called *hold back* policy and *complete pooling* policy, both which are often assumed in literature. Furthermore, we show that several model extensions fit in the same modeling framework, such as systems with substitutable items and order fulfillment problems in e-commerce.

***Keywords**: inventory management, spare parts, lateral transshipments, optimal policy, multiple demand classes*

Optimal Ordering and Disposal Decisions for Products with a Fixed Shelf Life

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In this study, a periodic review inventory model for a product with a fixed shelf life (like foods) is developed. The demand of the product depends on its expiration date. At a specific time instant, before the end of the reorder interval, the product selling price is discounted, so its demand increases. The unsold items at the end of the reorder interval can be donated. Notice that according to EU the best destination for food surplus is to redistribute this food for human consumption where safe to do so. As part of the Circular Economy Action Plan, the Commission has adopted EU food donation guidelines in order to facilitate the recovery and redistribution of safe, edible food to those in need.

For the above model, the total cost is comprised of ordering, purchasing and holding cost. The revenue is comprised of sold items revenue (in initial and reduced price) while the donated products can generate indirect revenue by increasing the company's reputation. The aim of the model is to determine the reorder interval, the time instant to discount the product's initial selling price and the quantity that will be donated so that the profit of the system is maximized. The influence of different system parameters to optimal policy is highlighted through numerical examples.

Keywords: *inventory, disposal, discount, expiration date, optimal*

Product Quality, Eco-friendly Improvement and Pricing Decisions in a Two-echelon Supply Chain under Consumer Environmental Awareness

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Companies are increasingly realizing the benefits of adopting environmental responsibility and including it into their supply chain strategy and operations. This paper explores the effects of consumers' environmental and quality awareness on supply chain management. We consider a manufacturer-retailer supply chain. Besides the price and quality, the customer demand depends also on the eco-friendly level of the product. Both centralized and decentralized models are developed to maximize the total supply chain and individual members' profit respectively. Decentralized decisions are determined under Stackelberg game setting. Price, quality level and eco-friendly level of the product are considered as decision variables. The channel coordination problem between the manufacturer and the retailer is investigated using a two part tariff contract. Surplus profit generated through coordination is distributed between the players using the concept of asymmetric Nash bargaining. The models are illustrated through numerical examples. The sensitivity of model parameters and the managerial implications are also examined.

Keywords: *eco-friendly supply chain management, product quality, Stackelberg game, coordination, Nash bargaining*

Searching for Evidence – the Impact of Digitization on Inventory Performance

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Objectives: There are a lot of discussions nowadays about the impact of digitization, and in particular, industry 4.0 on the economy and the society. Radical transformations are expected on short and medium term in both production and logistics. Due to connectedness (internet of things) and enormous amount of data, mass production will be replaced by customization or even more, by personalization. These changes are supported by various digital technologies, like sensors, RFID, big data analytics, 3D printing, which provide traceability, scrap prevention, predictive maintenance, smart products and services. They also have significant impact on inventory management, and related operational measures (e.g. inventory turns, quality, lead time). Despite the increasing interest in literature the evidences presented, are much less. The objective of this paper is to find evidence for how digitization impact inventory related performance measures.

Method: In our paper

a) we provide a *structural overview* about the relationship of inventory related performance measures and digital technologies. Understanding these relationships can help us to identify the technologies and industries, which are affected the most from the aspect of inventory management.

b) Based on an international database (DESI) we analyse the extent of using digital technologies in the industries selected in a) in the timeframe of 2014-2017.

c) Finally, using a detailed Hungarian panel database we show with detailed analysis how the relevant performance measures have changed in some companies and industries ahead in digital transformation.

Results: We have the databases but not yet made the analysis. We expect that the evidence we find is still marginal, since there are at the moment more talks than real activities in the field, except some big multinational players. Nevertheless, basic digital technologies already have spread slowly in the last decades and things have speeded up lately.

Conclusions: Our analysis can provide evidence on the extent of real changes in the performance of inventory management.

***Keywords**: digitization, inventory performance, DESI, evidence*

Service Levels in Supply Chain Inventory Systems

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Many mainstream supply chain inventory control models optimize stock levels subject to service level constraints that ensure a certain customer service performance. There exist different types of service levels like stockout occurrence and stockout magnitude related measures. One major shortcoming of these measures and the way they are applied in inventory models is that most definitions use expected service levels and as a consequence, performance measured empirically and for a given time horizon will deviate from prescribed levels derived under steady state conditions. Further, there exist inconsistencies between certain types of service measure and the assumptions concerning the materials flow. For example the almost exclusively used first-come-first-served assumption of satisfying backorders can be improved by different backorder management rules as will be illustrated in this paper. Additionally, the paper provides analytical expressions for service levels and a numerical study to show the potential for service level improvement.

Setting Stock Limits for Vendor Managed Inventory

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Vendor managed inventory (VMI) agreements are a supply chain collaboration principle in which the supplier is responsible for keeping the inventory at the buyer between given lower and upper inventory limits. The freedom and information sharing inherent in VMI may allow suppliers to more efficiently ensure availability at the buyer. But the VMI setup also implies that different suppliers may apply different approaches for staying between the limits. Relatedly, the objectives of a supplier are not completely aligned with those of the buyer. We develop methods that can be used by the buyer for setting appropriate lower and upper inventory limits while taking into account a heterogeneous supplier base. To this end, we identify four supplier types by distinguishing between various approaches for staying within the inventory limits and various possible supplier objectives. We develop a methodology for classifying suppliers into one of these four types based on historic inventory trajectories. We subsequently argue how to set inventory limits tailored to each supplier type. We report on a case study of the approach at a large buyer that is active in high-tech manufacturing. We verify that the approach can successfully identify the various types of the 47 VMI suppliers of the buyer. Finally, we show that tailoring inventory limits to the suppliers' types leads to considerable cost savings.

Keywords: *inventory, vendor managed, consignment, stock limits, clustering*

Simulation-Based "Total Cost of Ownership"-Analysis for Network Design – Investigating the Impact of Inventory-Related Costs

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Complex structures, a lack of transparency and uncertainties complicate the planning of global logistics and production networks. A holistic approach is needed in order to evaluate planning alternatives for network design. As a cost-based and holistic framework the so-called "Total Cost of Ownership" (TCO)-analysis has been adapted to various applications but has also been criticised as a static snapshot neglecting cost variations over time. This disadvantage can be overcome by a simulation approach, which allows for the analysis of cost developments, interdependencies and demand volatility from a dynamic perspective. Simulation-based TCO-analysis has been applied to the manufacturing context such as modular assembly systems but not yet to network design. Based on this research gap, the objective of this study is to develop a multi-period simulation model for a monetary and activity-based TCOanalysis for alternative network designs. The potentials of the TCO-approach with a focus on inventory-related costs are evaluated with two research questions: Is the simulation-based TCO-analysis applicable to complex networks? How does the impact of inventory-related costs differ for alternative network designs?

We develop an agent-based simulation model including options for local or global sourcing and different distribution channels. Real-world data from a pharmaceutical company is used to investigate three network designs for three exemplary products focusing on direct production costs, transport costs, storage costs and inventory carrying costs.

Results of the simulation experiments confirm the simulation-based TCO-analysis as a tool for visualisation and enhancement of transparency. Moreover, the adaptability to different geographical configurations, consideration of dynamic influences and different product characteristics are identified as benefits. Comparisons of cost components for the three network designs demonstrate the monetary impact of inventory-related costs and help to define proper safety stock levels.

In conclusion, the simulation-based TCO-analysis is evaluated as a valuable approach to aid the decision-making process for network design. However, it requires extensive company data which appears to be an obstacle in practice. Furthermore, the approach is limited to "greenfield" planning and not suited for reconfiguring existing networks. Though, this limitation can be overcome when set-up costs for network designs are considered as a next step.

Keywords: *total cost of ownership, inventory-related costs, network design, agentbased simulation, dynamic analysis*

Sustainable Supplier Selection Problems Considering Inventory Costs in a DEA Model

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We investigate a green supplier selection problem. We generalize our results of green supplier selection problem (Dobos-Vörösmarty, 2018). In our former paper we have developed a DEA-type supplier selection method where the output variables of a DEA model were the environmental factors and inputs of the analysis were the management variables.

The new model examines the effect of inventory related costs, such as EOQ costs of inventory holding or ordering costs, on the selected supplier. Another question is, how influence the lot size of an inventory model of the supplier selection process, not only the magnitude of the inventory level, but also the cumulated inventory related costs. We generalize our paper of 2018.

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

Acknowledgement: *The authors are supported by OTKA K 124644*

The Effects of Selected EU Level Regulatory Measures to Organic Cereal Supply Chains – Obstacles for New Solutions and Structures?

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The economic situation of the European farming sector in all member states as well as in Finland has been deteriorating during the last decade. Obviously, the root causes of this can be structural e.g. the small average size of agricultural holdings, but also situational e.g. the annual crop yield variation and the global market prices. Compared to many industries, there are two interesting characteristics in agriculture and especially in cereal supply chains. Firstly, the regulation of agriculture can be depicted exhaustive. Secondly, compared to downstream operations, the food industry and retailing, the negotiation power of the farmers is very often nearly non-existing. Supposedly, farmers could achieve size-related advantages with cooperation, but especially the cooperation of cereal farmers in Finland is hardly existing.

This study aims to find relationships between cooperative supply chain operating models and selected recent EU-level regulation effective to all member states. The study focuses on the organic regulation and organic cereal supply chains based on the recent and ongoing large-scale developments in the regulation to be implemented in Finland.

The study is carried out by bringing together the organic farming, supply chain management and EU organic regulation expertise. Firstly, the study presents the agreements used in the industry as well as material flows, inventory management and other supply chain characteristics of the organic cereal supply chain in Finland. Secondly, a set of potential new structures and practices for organic cereal supply chains are adopted from SCM theory and industries outside agricultural practices. In the final analysis, the developed potential supply chain structures are reflected against EU-level organic production regulation implemented in Finland. As a result, the focal regulatory issues inhibiting or hindering the adoption of new supply chain structures, roles and practices are pointed out.

To MTO or to MTS, for That Is the Question

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Inspired by a company requiring a simple decision framework for deciding which items to make to stock and which items to be made to order we propose a dynamic selection process to inform that assessment. We also present a conceptual model that ties the MTO/MTS decision to the products life cycle. The decision framework is dynamic in that the process is carried out at regular intervals, at a rate that best suits the manufacturer. This allows the MTS/MTO choice to reflect the products changing demand behaviour, so that it shifts between being MTO or MTS depending on its current state. Although there is a body of work on various decision frameworks, little, if any, focuses on how the decision to MTO or to MTS can change as the products change their demand characteristics. This led to the insight that shifting between manufacturing states reflects the stages in the products lifecycle, such that a demand planner could use this as a heuristic to determine if a product should be made to stock or to order. We demonstrate this with actual product demand histories from the company we worked with. Both with using the simple dynamic selection process and using the product life cycle heuristic.

Performance Measures, Sensitivity Analysis and Comparison of Inventory Models

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Inventory models may contain a large number of parameters that might be deterministic or stochastic (e.g. demand, leadtime, costs). Hence, the solution of this kind of models is generally obtained through approximations. Analytical solutions are rarely available and may only be obtained numerically or by simulation. Additionally, the parameters of the model are usually estimated from empirical data by means of statistical methods, which represent additional perturbations.

For the single-echelon single-product inventory model with stochastic demand, two control policies are popular. The (s,S) policy is optimal in many cases under mild conditions. However, an (s,Q) policy is sometimes preferred in practical settings because it might only be possible to order a fixed quantity. There are barely any studies that explore the difference in terms of costs and service level of the two policies.

In this paper, we model the above-mentioned inventory policies by Markov chains and analyze them using results from perturbation theory. By considering generalized inverses related to the inventory Markov chain transition matrices, we explicitly calculate the stationary probabilities of the inventory position in each case and derive exact formulas for the cost and service measures (e.g. fillrate). Furthermore, we investigate the effect of small perturbations in the input parameters of the model (e.g. demand distribution) and derive upper bounds to the resultant deviation in the characteristics. Finally, we estimate the difference in terms of cost and service levels between the (s,S) and (s,Q) inventory policies and provide numerical examples.

The derived results show that the (s,Q) inventory model is more resistant (insensitive) to perturbations than the (s,S) one although both are robust. Additionally, applying the optimal policy, i.e. (s,S), might not generate enough advantage to justify the preference over an (s,Q) policy.

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Spare Parts or Buffer? How to Design a Flow Line with Unreliable Machines

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Manufacturing systems consist of several machines often connected with material flow systems. If machines are subject to failures and breakdowns, then often buffers are installed to decouple the machines and to avoid a production stop of the whole system. In this paper, we additionally allow stock keeping of spare parts in order to enable fast repairs. As a consequence machine availability as well as the isolated production rate is increased, which results in a larger throughput. We model the system as a Markov Chain to enable the computation of the steady state probabilities and all relevant performance measures. Further, we also present an approximation to compute optimal system designs fast. We investigate the interrelation between spare parts provisioning and buffer size and show how the optimal system design depends on the cost for spare parts and the cost for buffer places. If the same parts are responsible for the failures in all machines, then spare part provisioning is getting more attractive due to the pooling effect.

Mathematical Models of Inventories

A Dynamic Programming Approach for the Stochastic Inventory Routing Problem with Backorders

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This paper considers a dynamic stochastic inventory routing problem with backordering (DSIRPB). The demand is stochastic as it is known in a probabilistic sense and considered dynamic because the demand is gradually revealed at the end of each period. This work is an extension of stochastic inventory routing problem where the stock-out is replaced with backorder decision. The DSIRPB distribution network consists of a supplier and a set of retailers. A limited number of single product is assumed to be produced by the supplier. An order-up-to level inventory policy is adopted to control the unmet demand. If there is an unmet demand after the realization, the unmet demand is backordered and fulfilled first as soon as the retailer is served in the next period. The transportation is handled by a third party where a capacity C, is bought at each period t. DSIRPB aims to minimize the total expected cost which includes the inventory cost at supplier, inventory and backordering cost at retailers and transportation cost. The DSIRPB is modeled as dynamic programming where the state in the period t is represented as the inventory level for the supplier and all the retailers. As the dynamic programming formulation cannot be solved exactly because it suffers the curses of dimensionality, a hybrid rollout algorithm is proposed to overcome the problem. A new mixed integer linear programming (MILP) formulation is proposed to obtain the approximate cost-to-go, $\tilde{J}_{t+1}$. The hybrid rollout algorithm is enhanced by proposing an additional control based on Artificial Bee Colony (ABC) algorithm. The performance of the enhanced hybrid algorithm is tested on an existing benchmark problem where a uniform probability distribution of the demand is considered. The expected costs found are compared with bounds found by CPLEX, and additionally, an analysis of the controls is carried out. On average the ratios between the cost found and the bounds are 0.316 and 0.48 for 3 periods in low and high inventory cost respectively. ABC controls contribute on average 90.22% and 97.56% to the best-expected cost found for low and high inventory cost. The patterns in the delivery quantities and number of visits are observed and analyzed, where the number of visits are inversely proportional to the backorder quantities. The small ratios of the bounds and the expected cost found shows the effectiveness of the algorithm in solving DSIRPB. It is shown that ABC controls contribute better controls to the best-expected costs.

Keywords: *inventory routing, stochastic demand, dynamic programming, matheuristic*

A New Heuristic Policy for Lost Sales Inventory Systems

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We argue that, when developing heuristic policies for lost sales inventory systems, we should adhere to a number of design principles. Based on recent literature, we propose the following principles: 1) The policy should perform increasingly well when lost sales costs are high; 2) the policy should perform increasingly well when the lead time grows large; 3) The policy must be easy to compute for arbitrary systems; 4) The policy must be easy to explain. We will then report on ongoing work that attempts to find a heuristic policy that satisfies these design principles.

A Reverse Logistics System when Items Return with Cycle Dependent Quality and Remanufactured Items Are Sold on Quality Dependent Markets

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We study an integrated production–inventory system that manufactures new items of a particular product and receives some of the used items back after a period of use. These can be either remanufactured on the same production line or disposed of. Used items awaiting remanufacturing need to be held in stock. Both manufacturing and remanufacturing operations require setting up the production equipment. Remanufactured items can be less costly to produce, yet they are considered as sold on a different quality markets and serve the product demand. New and remanufactured items are kept in stock, from which the product demand on different markets is satisfied.

Controlling such a system involves decisions with regard to disposal of used items, succession of manufacturing and remanufacturing operations, and lot-sizing. Existing research has studied control policies for such production–inventory systems in a variety of settings. Specifically, beginning with the work of Schrady (1967) and Richter (1996), significant attention has been devoted to settings with constant demand and return rates. More recent work referred to settings assuming variation in quality of returned items and a limited number of remanufacturing cycles an item can undergo. We extend this line of research by studying a setting, in which items return in a quality condition that depends on the number of remanufacturing cycles an item has undergone and determines the holding costs of that item.

A Two-echelon Inventory System under Trade Credit: "Integrated versus Non-integrated Models"

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Traditional inventory models are based on the assumption that the supplier is paid for the items immediately after the buyers receive them. However, in real business transactions, buyers are not forced to make the payments to the vendor when they receive the items. It is very common that the vendor allows the buyers a credit period for setting the amount owed. Indeed, nowadays trade credit is an increasingly general payment behavior and for the buyers it is an important source of external financing.

In the last few decades, inventory models under permissible delay in payments have been widely studied for many researchers. Nevertheless, most of related works focus on the single-vendor single-buyer system. The objective of this paper is to extend the analysis to the two buyers case. It is well known, that in general, the total cost of the system is reduced when the buyers and vendor cooperate and there is a unique decision-maker that manages the whole supply chain. Hence, we first address the problem under such assumption and an integrated model is presented. In addition, we are also interested in comparing the integrated solutions with those obtained when a decentralized decision-making process is considered. Thus, we also formulate the problem assuming that the buyers and the vendor make decisions independently.

In the first case, we show that the problem can be formulated as a mixed non-linear programming problem. Regarding the non-integrated model, we propose a two-level optimization approach consisting of computing first the order quantities at the buyers and then determining the shipment schedule at the vendor. We carry out a computational study and a sensitivity analysis to study the effect of the different model parameters on both integrated and non-integrated costs. From the results, we can conclude that in general the integrated procedure provides better policies than the non-integrated approach. Only when the replenishment costs at the buyers are high the non-integrated model yields more efficient solutions than the integrated model. In contrast, when the replenishment cost at the vendor increases, so does the benefits of following an integrated policy instead of a non-integrated one.

Keywords: *Inventory model, trade credit, one-vendor two-buyer system, integrated policy, non-integrated policy*

A Two-level Joint Production Lot Sizing Problem with Non-conforming Items and Learning

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Companies have to account for the constantly evolving technologies which are driven by the consumer's appetite for new and innovative products. Accordingly, production systems have to account for producing non-standardized products with new specifications. Due to the novelty of the product, a considerable proportion of the items produced from the supplier's production process is assumed to be imperfect and does not conform to the company's specifications. We consider a two-level joint production system which investigates the behavior of the supplier and the buyer's production systems. We assume that the proportion of nonconforming items produced by the supplier is subject to learning and improves with every batch. The proportion of non-conforming items shipped from the supplier to the buyer is random with a mean and variance dependent on the learning level of the supplier. We examine investing in the supplier's process to speed up the learning process. Investing in the supplier's process can be in the form of training the supplier by delegating workers. Due to the short market lifetimes of the product, we consider a finite horizon inventory system which solves for the optimal production quantities while accounting for the random nature of the proportion of defective items. A numerical study is presented to quantify the impact of learning on the production system as well as the cost saving incurred by investing in the supplier's production process.

An Adaptation of Capacitated Lot-Sizing Models to Deal with Facility Planning in a Scenario of Budget Reduction

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In many countries, the financial pressure on government funding of services such as health care, waste collection, libraries, the fire and police services, is likely to continue for the foreseeable future. As consolidating services through reducing the number of locations or the number of hours they are open can often lead to significant cost savings, this is an approach that is frequently chosen to mitigate financial shortfalls. However, while many location-allocation studies can be found in the literature, there is a lack of studies developing congestion considerations in a scenario of supply reduction.

In order to fill this gap, our study tackles the problem by developing a multi-period model (inspired by the mathematical formulation of the Capacitated Lot-Sizing Problem) for a multi-facility network, focusing on the possibility of having demand transfers across facilities with financial limitations in a congested environment. The model is able to identify possible users' flow and movement throughout the system. The risks from reorganisation can be highlighted and suitable decisions can be made. The model is tailored according to a real-world case (the optimisation of recycling centres in a large city in the UK).

Keywords: *Capacitated Lot-Sizing, Facility Location, Congestion, Facility Reorganisation, Mathematical Modelling,*

An Economic Production Quantity Model with Work-In-Process Inventories

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Several extensions of the classical Economic Production Quantity (EPQ) have been proposed in the past, but only few of them considered Work-In-Process (WIP) inventories. When considering manufacturing and/or process systems, these inventories may represent a significant, as well as strategic, inventory cost. In particular, processing raw materials to obtain finished products requires significant investments of resources and processing times, thus giving evidence to the critical issues linked to the WIP growth. Therefore, when calculating the optimal production batch size in cases, e.g., of long processing times, it may be worthily to consider the holding costs due to the WIP piling, along with raw materials purchasing and the inventory of finished products.

Starting from a literature analysis and some industrial cases of reference, the present contribution proposes a new EPQ model, encompassing the Work-In-Process inventory, in a complete systematisation of the company inventories, defined as EPQ-WIP model. Depending on different industrial applications (e.g. milk processing, rubber manufacturing, etc.) different variants of the EPQ-WIP model will be analytically investigated and compared, initially starting from the classical EPQ hypotheses and, then, progressively introducing new features and removing hypotheses, so as to consider different productive situations.

Finally, a numerical analysis will show the impact of the proposed model, when compared to the basic EPQ approach, thus leading to managerial and applicative considerations. In fact, the savings related to the adoption of the EPQ-WIP model, allowing a better detail of the system cost components, will be compared to the results determined by the classical EPQ approach.

Keywords: *EPQ; raw material; work-in-process; inventories; industrial processes*

An Embedded Newsboy Problem Supporting Inventory Level and Allocation Decision in Publishing Industry

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The paper analyze an initial inventory level and allocation decision in a project based industry, book publishing. A dyadic supply chain with a manufacturer (publisher) and a retailer is investigated. The manufacturer produces a homogenous product (books) and allocates a certain amount of this product, as initial inventory to the retailer. The retailer reports the number of sold books to the publisher at the end of a given time period. The payment is based on the quantity reported by the retailer to the publisher.

The inventory level and allocation decision of the publisher is modeled as an embedded newsboy problem. The decision variable and four probability functions in the model are:

- Q_a quantity allocated by the publisher to the retailer at the beginning of the period, decision variable,
- Q_s quantity sold by the retailer within the period,
- Q_r quantity reported by the retailer to the publisher, and
- Q_p quantity paid by the retailer to the publisher at the end of period
- M margin paid by the retailer to the publisher

The aim of the paper is to determine an initial inventory level at the retailer allocated by the publisher which minimizes the costs and maximizes the margin in the embedded newsboy problem.

The second part of the paper present a real world application of the constructed model in the case of a book publisher and a retailer.

Keywords: *newsboy problem, optimization, inventory control*

An EPQ Model with Variable Demand Rate, Setup Cost, Production Cost, and Holding Cost

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The Economic Production Quantity (EPQ) model was developed assuming the demand rate, the setup cost, the unit holding cost, and the unit production cost are all fixed constants. However, in most practical production environments, these assumptions do not accurately reflect reality. Quite often, the demand rate for a particular product is affected by several factors such as its price, length of its storage time indicating its freshness, and its stock level indicating its immediate availability to customers. Inventory models in which the demand depends on the selling price are based on the assumption of demand elasticity, i.e. the lower the price, the higher the demand.

Moreover, assuming that the costs of holding, production, and setup are fixed constants may not be always valid due to several reasons. First, the more an item is kept in stock, the more the energy consumption, material handling, and manpower efforts needed to preserve its condition, which increases the unit holding cost. Second, human resources and raw materials are used more efficiently with higher production rates. Therefore, processes with high production rates usually have low unit production cost. Third, the effort and time needed to perform a set-up activity are related to the condition and automation of the production process. For high production rates, the production process is likely to be performed by more sophisticated and expensive equipment, resulting in higher set-up costs. Therefore, processes with high production rates generally require higher setup costs than those with low production rates.

In this paper, several simplifying assumptions of the EPQ model are removed. An EPQ-type model is proposed in which the demand rate, the setup cost, the unit production cost, and the unit holding cost are not constants but dependent variables that change according to specific functions. The demand rate is a decreasing function of the selling price. The setup cost per production lot is an increasing function of the production rate. The production cost per unit is a decreasing function of the production rate. Finally, the unit holding cost is an increasing function of the storage time duration. These assumptions have not been simultaneously considered in previous literature. A mathematical model is formulated to determine the optimum selling price, production rate, and cycle time. An efficient solution algorithm is developed to maximize the total profit.

Keywords: *EPQ model, price-dependent demand, time-dependent holding cost, variable production cost; variable setup cost*

An Operational Form of Bundling

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Abstract: Our objective is study a newly proposed form of bundling that is operational and dynamic. This is in contrast to the conventional notion of bundling that has always been assumed to be fixed within the realms of economics, operations research and marketing literatures. To begin, we consider two major product line strategies where the firm sells individual goods and, typically at a discount, a bundle of all or a subset of these goods. We shall call them partial mixed-bundling and mixed-bundling. To illustrate, we consider a firm selling two items (we shall call them focal and non-focal item) and is risk neutral, i.e., profit maximising. These two forms of bundling options can be differentiated according to the various level of sales restriction. For partial mixed-bundling, the firm mandates the purchase of the focal item that must be tied with purchasing the non-focal item and is equivalent to tying. For mixed-bundling, the tying requirement is removed and the focal item becomes available individually. In the situation where where the retailer does not provide a discount and therefore, mixed-bundling is equivalent to unbundling or pure component (Prasad et al 2010). With our new form of operational bundling that straddles these two bundling regimes, our roadmap analysis consists of framing an optimization problem. First, we shall prove that it is possible to reduce the complexity of the optimization problem without loss of optimality. Second, we compute the stationary probability of the joint inventory level and develop the long-run average payoff rate. Third, we characterize the information structure for optimal dynamic bundling. Some other results from our work include static bundling is optimal whenever the product of holding costs and order-up-to level for the focal item is sufficiently small, otherwise dynamic bundling is optimal. We will also determine the optimal order-up-to levels for each item. In conclusion using the various inventory costs and price, we debunk the idea that bundling (if it can be applied without costs), should always be fixed when selling occurs over a long horizon.

Keywords: *inventory, bundling, optimisation, Markov-chain, operations management*

Analyzing Selling Strategies in a Sustainable Supply Chain under Versioning

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In this article, we develop a supply chain model for organic and conventional versions of an agricultural product in which a retail price, whole sale price, sustainable level and quality of items are decisions variable. It is assumed that benefits, which are generated by selling items, will be distributed among customers, based on a random variable. Increasing the demand and attractiveness of the product for customers are based on product quality, price and stability and compatibility. It's also worth noting that each plant is losing carbon in the event of carbon leakage, but the government allocates a certain amount of carbon emissions to each plant, which will be allocated according to a state law according to capacity and balance. The pricing decisions of a retailer will be considered according to the product's quality and shelf life.

According to the assumptions, the degree of product compatibility with the environment is determined, most importantly, choosing the type of distribution channel will have a significant impact on these variables. We consider three sales channels for selling our products including the retail distribution channel (R), the direct sales channel (M) and, finally, our third segment includes two channels, a retailer and a direct channel (MR). There are two retailers, each offers a particular version of the product and compete together. Both symmetric and asymmetric distributions of power are investigated and different structure of power will be studied.

Market demand will be a linear function of decision variables. We consider the game theory approach under different channel structures in order to determine the optimal values of decision variables. Finally, results are analyzed by numerical examples to determine the profitable structure for the problem.

Keywords: *Price, Quality, Sustainability, Game Theory, Supply Chain*

Base-stock Optimization of the Hidden Markov Model for an Inventory with Poisson Demand, Non-crossing Lead Times and Lost Sales

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Johansen (IJPE 2005) has applied a hidden Markov model to obtain important results about the base-stock policy for the studied inventory supplied by an exogenous and sequential system with Erlangian lead times. The previous model is extended to include the setting where the lead times of the supply system are the sum of exponential variables with possibly different means. My favorite is the Extended Erlangian (EE_r) lead times for which this sum has r terms and at least r-1 of these are exponential variables with the same mean. Assuming that the coefficient of variance for the lead times is at most one, it is shown how the parameters of the EE_r can be expressed in terms of the mean and the variance of the lead times. For fixed base-stock S, the computation of the average cost C(S) per unit time is described. Because C(S) is convex in S, it is straightforward to compute the optimal base-stock and the minimum average cost. Like in the 2005-paper, a numerical study illustrates that the minimum average cost is very sensitive to the variance of the lead times, which is in sharp contrast to the complete insensitivity when the lead times are independent.

Keywords: *base-stock policy, non-crossing lead times, Erlang, lost sales*

Controlling Distribution Inventory Systems with Time Based Shipment Consolidation and Compound Poisson Demand

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Motivated by collaboration with a large European company in the construction industry, we consider a one-warehouse-multiple-retailer inventory system subject to compound Poisson demand. Deliveries from the warehouse to groups of retailers are consolidated using a time based shipment consolidation policy with periodic dispatching and fixed costs per shipment. The resulting shipment intervals increase the lead times for the retailers and their need for safety stock. Thus, a trade-off exists between shipment costs and holding costs. Our aim is to optimize the periodic shipment intervals and the reorder levels at all stock points to minimize total costs, both in the context of a backorder cost model and a fillrate constraint model. In coherence with the situation at our focal company, we assume complete backordering and first-come-first-served allocation. Moreover, the lead time from the outside supplier to the central warehouse and the transportation times from the warehouse to the retailers are constant. Previous work has focused on exact solutions, which are computationally demanding and only applicable for small problem instances with few retailers, small demand quantities and few retailer groups. Our focus is on developing computationally efficient heuristics that can be used for real world problems with many retailers, highly variable demand quantities and many retailer groups. We present one heuristic for the backorder cost model, and one for the fillrate constraint model that our focal company uses. A numerical study of 256 small problem instances illustrates that the proposed methods perform well compared to the existing exact cost minimizing solutions. The approximation method for the backorder cost model provides solutions that are on average 1.7 % from the optimal cost. For the fillrate constraint model, the average deviation from target fillrates is 0.14 percentage points (pp) and the maximum is 1.4 pp. Moreover, using real data for 75 items from our focal company, we show that the methods are appropriate for solving real world problems that the exact methods cannot handle. The obtained policies are evaluated and compared to the company's current solutions using simulation. The results show that large improvements can be achieved, both in terms of reduced costs and better fulfillment of target fillrates. With regards to the latter, our solution render an average deviation from target fillrates of merely 0.25 pp.

Keywords: *stochastic, inventory control, multi-echelon, shipment consolidation, compound Poisson demand*

Decomposition-based Optimization of a Deterministic Two-echelon Inventory Chain

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We consider a two-echelon serial supply chain facing fixed-rate deterministic demand. Depot and retailer use periodic review base stock (S,T) policies, whose review intervals are nested; so they satisfy an integer ratio relation. Inventory holding and backorders (at the retailer) carry linear penalty costs, while replenishments at each echelon are charged by a fixed cost. We seek the order up-to levels and review intervals at both echelons that minimize average total cost (per unit time). Using echelon inventories and cost rates, we first model the system cost function. We then show (in line with stochastic systems) that, for any fixed review intervals, the classical Clark-Scarf decomposition (and the associated Newsvendor equations) holds; so, the partially optimal order-up-to levels at both echelons (as functions of the review intervals) are directly determined. Further, invoking a convexity property, the respective optimal review interval at the retailer can also be obtained, leading to a final partially optimal total cost function only depending on the depot review interval. Using a lower bound originally proposed for stochastic systems, global optimal is reached via a limited one-dimensional search. Interestingly, most optimal variables and system cost are obtained in closed-form, directly related with the single-echelon EOQ solution. Finally, we present analytical properties of the optimal solution and use numerical computations to investigate some interesting system design issues.

Keywords: Multi-echelon; Inventory; Optimal; EOQ; Supply chain

Fill Rate Approximations for a Lost Sales Environment

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When controlling their inventories, retailers are typically confronted with consumers substituting to an alternative product if their preferred product is out of stock. Finding the right reorder levels in the periodic review inventory management system for these lost sales environments with fixed case pack sizes is a challenge. In the scientific literature this problem is known to be very hard to solve. While in the last ten years new approximations have been developed, we will show that still significant improvements can be made. Discounters or retailers offering a very wide range within a product category may aim for a relatively low target service level on the SKU level for part of their assortment (especially for perishables), as long as the product availability at the category level is sufficient. For this type of retailers we will show that the existing approximations are not always adequate, especially if ordering is done in an integer number of case packs. Based on a mathematical analysis of the problem, we will provide new approximations, which work well for this type of retailers as well as for retailers aiming for high service levels.

Keywords: *inventory, periodic review, lost sales, reorder level, lot-sizing, retail*

Green Supplier Selection and Order Allocation with DEA

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Supply management has a goal to identify the suitable suppliers. A next problem is to choose the lot size of a supplier in a supplier order selection problem. The aim of the paper is to combine the supplier selection problem with supplier selection criteria with lot sizing decision.

The solution of the mentioned problem leads a two stage decision making problem:

1. supplier selection with green criteria, and
2. lot sizing for the chosen suppliers.

In the first phase we use data envelopment analysis to select the suitable suppliers and in the second phase we apply an economic order quantity to specify the lot sizes. The supplier selection criteria are based on an extended sustainable criteria system.

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

Acknowledgement: *The authors are supported by NKFI K 124644.*

Incentivizing Suppliers in Vendor Managed Inventory Contracts

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In high-tech manufacturing, we observe long-term interaction between the manufacturer and his suppliers. In this setting, we study Vendor Managed Inventory contracts between supplier and manufacturer. Such contracts make the supplier responsible for maintaining inventory at the manufacturer's site. Since failure to satisfy customer demand leads to high penalties for the manufacturer, he wants to incentivize his suppliers to keep sufficient inventory. We investigate the possibility of providing a bonus to the supplier if he performs well. The question is how the value of this bonus should be determined, such that the supplier will keep sufficient inventory. This situation is modeled as a Stackelberg game, in which the manufacturer is the natural leader and the supplier is the follower. We present some preliminary results.

Keywords: *Stackelberg games, Vendor Managed Inventory (VMI), long-term relations*

Integration of Ergonomic Aspects into Lot-sizing Model Based on Relaxation Allowance and Endurance Time

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The maximum endurance time is a key parameter for estimation of relaxation allowance and rest times. The aims of this study are; extension and development a cost model based on relaxation allowance and endurance time formulations are developed by Rohmert (1960,1973) which is take account of rest time periods that help to maintain low levels of fatigue and ergonomic risks; to investigate the effects of endurance time and relaxation allowance on the total cost of logistics operation and the classical EOQ model and comparison of the findings with the other cost model which covers relaxation allowance. In this study, maximum endurance time and relaxation allowance integrated to the cost model for investigation of effects on the total cost of the logistics system and reducing the ergonomic risks. The problem studied in this paper is a case of production line supply process, which covers transportation of fixed amount of raw materials from storage plant to production plant by manual material handling with simple cart and the study covers picking, storing, pushing and pushing back with empty cart for manual handling of the products. The developed model considers the maximum endurance time for calculation of rest time necessary for different quantities of handled items and item weights. The model is applied in a numerical study with realistic, but randomly generated parameters. As a result, parametric analysis results showed that higher the weight of the item, the lower is the lot size (q) and the higher the especially the total cost and cost of rest time required for reducing ergonomic risks. The comparison results indicated that both models implemented show higher or lower increase with the growth of the lot size because increasing the effort spent for each picking, storing and pushing activities will increase the rest time for recovery of muscles and increase the ergonomic working conditions. The comparison with traditional cost model (EOQ) implemented that our model percentage saving from using ergonomic rest time and maximum endurance time equals to 13,55% in the total cost of production line supply process. Finally, the developed model analysis results were shown that the developed method using the rest allowance concept with maximum endurance time is suitable to integrate ergonomic aspects into a formal inventory cost model.

Keywords: *ergonomics, manual material handling, endurance time, relaxation allowance, intralogistics*

Inventory Control in Distribution Systems with Quantity Based Shipment Consolidation

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Shipment consolidation policies offer a potential to increase capacity utilization of transport vehicles and thereby decrease transportation costs and emissions. However, increased shipment quantities suggest longer lead times. This means more inventory is needed or a reduction of service level will occur. Joint consideration of inventory and transportation/shipment decisions in the design and control of distribution systems is therefore important

We consider these issues in a context of a one-warehouse-multiple-retailer inventory system with quantity based shipment consolidation to groups of non-identical retailers facing Poisson demand. The system is centralized, with free information sharing within an integrated supply chain information system that offers access to real-time point of sale data. Thus, the retailers experience no fixed ordering costs and act according to base stock policies. However, there are fixed costs associated with handling and transporting goods from the warehouse to the retailers, as reflected in the shipment consolidation policy. Stock replenishments at the warehouse are made from an outside supplier/manufacturer according to an (R,Q) policy. The lead time for warehouse orders and the transportation times between the warehouse and the retailers are constant. Moreover, complete backordering and FCFS allocation is assumed at all stock points.

The retailers are organized in groups to which shipments are consolidated and transported on a common vehicle. As soon as a retailer group has ordered a specific number of units, referred to as the shipment quantity, and these units are available at the warehouse, the shipment is released. This means that all shipments to a retailer group exactly corresponds to the shipment quantity, for example a full truckload, container or other type of load carrier.

For this system, we derive an exact recursive method for determining the inventory level distributions at the retailers and the warehouse. This allows us to evaluate the expected inventory and shipment costs, fill rates and transport emissions for the entire system. We also show how to optimize the reorder levels and shipment quantities and how to compare different transport options.

Keywords: *Inventory, multi-echelon, shipment consolidation, stochastic, transportation*

Optimal Allocation of Stock under Price Dependent Random Demand

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Objectives of the study: As customer markets become more complicated, an integrated analysis and optimization of decision problems become more important. The need for integrated optimization of ordering, pricing and allocation problems is even more evident in technology intensive products and services where the customer demand and customers' price sensitivity highly varies over the life-cycle of the product. In this talk we consider such a system, and build a model for finding optimal ordering, pricing an allocation decisions under random price dependent demand, and supply uncertainty.

Our model is applicable for a national distributor of a technology intensive product (say, for a brand of smart phones) where the market demand can be partitioned into two non-overlapping time segments. As the market demands occur in non-overlapping, consecutive time periods, we can refer to the time periods over which the primary (secondary) market demand is realized as the primary (secondary) sales season. In this talk our main focus is the optimal pricing of the product and the allocation of on-hand quantity to retail stores over the secondary selling season.

Materials and methods: In our analysis, we choose to maximize the expected system-wide profit of the distributor, and sequentially decide on the amounts to be allocated to retailers, the optimal sales price, and the replenishment amount of the distributor. One of the main ingredients of our model is the modeling of the demand function, where we employ an additive-multiplicative type price dependency.

Results and conclusions: We obtain near-explicit expressions for the optimal allocation amounts, the optimal centralized order quantity, and the optimal price. We investigate the behaviour of the expected profit function and the order quantities with respect to various system parameters.

Partial Pooling by Independent Firms with Allocation according to Contribution to Pool

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Objectives of study: Motivated by an inventory pooling strategy that is quite prevalent in practice, we develop a formal model of partially pooling inventories where two independent firms pool some of their inventory while keeping the rest at their local storage facilities. The pool is created by the firms' contributions, and a firm's entitlement for an allocation from the pool (if needed) is a function of its contribution. Here it will be assumed that use of other firm's units involves payment and transshipments between retail stores is prohibitively expensive. Costs of initial placement of units in the pool and stores may be different, and the model also includes transshipment costs from the pool to customers.

Materials and methods: We analyze the resulting non-cooperative game. First, we consider an example with discrete demand, and then explore a continuous demand model. We also compare the optimal partial pooling strategy to the special cases of no pooling and complete pooling and discuss situations where it is likely that one of the special cases will be optimal.

Results: We prove existence of a Nash equilibrium in the decentralized partial pooling model and compare it to a model with centralized control. An appropriate compensation cost for using the other firms contribution to the pool can induce the retailers to achieve centralized solutions. Numerical results confirm that under partial pooling the independent retailers can achieve higher expected profits than under no pooling or complete pooling.

Conclusions: Our results confirm that partial pooling can indeed significantly outperform no pooling and complete pooling, which indicates the practical relevance of pooling some, but not all, inventories at a central storage location.

Keywords: *newsvendor, partial risk pooling, non-cooperative game*

Production Planning for a Ramp-up Process in a Multi-stage Production System with Worker Learning and Growth in Demand

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With product life cycles becoming shorter and product variants increasing, production planners are more and more frequently encountering production ramp-ups in practice. During production ramp-ups, companies are often confronted with low production rates, slow setups, random machine breakdowns, and unreliable production processes producing defective items, which makes the ramp-up one of the most critical steps in a product's life cycle. To support production planners in managing the ramp-up as efficiently as possible, prior research has proposed several decision support models that assist practitioners in determining lot sizes or capacity investments, in assigning workers to different tasks that need to be completed during the ramp-up, or in generally managing the production workflow during this phase. The work at hand investigates the ramp-up of a multi-stage production system that produces a single item to stock. The item is produced in a production process involving some amount of manual work, which results in a learning effect at each production stage. Due to a gradual diffusion of the product in the market, end customer demand increases over time. For this scenario that frequently can be observed in practice, the work at hand proposes a decision support model for assigning production resources (workers) to the different stages of the production system and for determining lot sizes, taking account of the various interdependencies that occur between the production stages. The objective of the model is to continuously satisfy end customer demand at minimal cost. The paper further develops a solution procedure for the proposed model and investigates the behavior of the model in numerical experiments.

Keywords: *production ramp-up, production start-up, multi-stage production system, learning effect, demand growth*

Simultaneous Capacity, Production and Inventory Decisions under Demand Uncertainty in a Multi-Period Assembly System

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Capacity planning is a crucial problem in any manufacturing industry. In the semiconductor industry, however, this problem becomes particularly difficult due to a series of complicating factors, such as highly uncertain and non-stationary demand, short product lifecycles, exceedingly long lead times, high capacity investment costs along with irreversibility of capacity investment, and extremely complex production processes. While it is possible to use inventory to hedge against these factors, holding costs are high and thus careful planning is required. In this work, motivated by a real-world problem faced by a leading provider of lithography systems for the semiconductor industry, we address the problem of determining the capacity, production and inventory levels for all stages, subassemblies and components of an assembly system so as to minimize the expected cost for the planning horizon. Demand is characterized by a finite set of scenarios and demand surges are anticipated during the planning horizon. We model the problem as a stochastic dynamic program and draw meaningful insights regarding the interrelations among the activities, as well as when to use inventory as a substitute of scarce capacity.

Keywords: *capacity planning, assembly system, high-tech manufacturing, stochastic dynamic programming, scenario-based approach*

The Economic Production lot SIze Model with Continuous Adjustments of the Production Rate

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We study an extension of the economic production lot size model, where we at any time during a production run freely can use any production rate, subject to that there must never be a negative inventory. We assume the production costs per time unit c(v), when using production rate v, is a convex function, but otherwise we have the cost components as in the standard economic production lot size model. We show that if the function c(v) is linear then it is either optimal to use synchronous production or use an infinite production rate (simply the EOQ policy). For the case where c(v) is strictly convex we show how to establish a mathematical description of the production rate function v(t), as function of time t of a production run. For the case where c(v) is quadratic, it turns out that the production rate should be accelerated in a constantly pace and the higher the holding cost per unit time unit is, the higher is this acceleration. The paper extends earlier results published by Larsen (International Transactions in Operational Research, 2005).

***Keywords**: production and inventory control, production rate*

The Effect of GHG Emissions on Production, Inventory Replenishment and Routing Decisions in a Single Vendor-multiple Buyers Supply Chain

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Nowadays, competitive supply chains cannot disregard environmental issues. In fact, increasingly strict government regulations and a renewed customers' consciousness are pushing companies towards a more responsible way to conduct their business. This requires adopting "green policies" to manage all business processes (procurement, product development, production, etc.). Hence, a necessary condition for supply chains to be profitable is to make operations also environmentally sustainable. In a supply chain, all involved actors must cooperate to fulfil this purpose along with the not secondary objective of making profit. In this work, we study a two-echelon, single vendor-multiple buyers supply chain. The vendor supplies a single item type to buyers and act cooperatively with them. Each buyer faces a stochastic demand and adopts a standard continuous review, lot sizereorder point policy to manage the item inventory. The vendor manufactures each lot at a finite production capacity and then ships the item to the buyers situated in different locations by using a fleet of identical vehicles. Both production and transportation of goods are responsible for greenhouse gases (GHG) emissions. A cost model is developed which includes setup and ordering costs, stockholding cost, shortage cost, emission cost, and transportation cost. Two emission regulation schemes are considered: cap-and-trade and tax. The objective is to minimize the long-run expected joint total cost per time unit to find the optimal production, inventory replenishment, and routing decisions. In particular, the decision variables considered in the model are production rate, order quantity and reorder point of each buyer, number of shipments from vendor to buyers, and a collection of delivery routes that specifies both the number of routes and the buyers served in each route. The optimization problem is tackled by means of an iterative two-phase approach. The first phase of the solution method considers the production-inventory replenishment optimization problem; the second phase concerns the solution of the vehicle routing problem taking in input the output of the previous phase. Both phases are repeated in sequence until a stable solution is reached or a termination criterion is satisfied. Numerical experiments are finally performed to investigate the effect of combinations between different emission trading schemes. This makes it possible to outline managerial implications and insights.

Keywords: *supply chain, inventory, greenhouse gases, emissions, environment, optimization*

Empirical Evidence for Inventory Theories

/special session/

A Study of Performance Measurement in the Oil and Gas Supply Chain

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There is evidence in the literature to suggest that the usage of performance measurement framework (PMF) is important to proper control and management of organisations. The usage of PMF helps organisations in gaining a competitive edge. Therefore, in this paper, we use Resource-Based View (RBV) as a theoretical lens to understand the contributions of PMF to overall organisational competitiveness. In addition, this paper explores the prevalence of performance measures in the oil and gas industry and their impacts on organisational performance. A questionnaire survey was designed including a list of performance measures drawn up from a combination of literature review and interview-based exploratory study. The questionnaire was then administered to 550 oil and gas companies in the UK and 120 similar organisations in Malaysia. The survey resulted in a total response rate of 17%. The data was analysed using SPSS 21 for Windows. The results reveal the prevalence of performance measures in this industry based on the level of importance. The results further indicate the relationship between the choice of performance measures and organisational performance indices.

Keywords: *performance measurement framework, performance measures, supply chain, oil and gas, resource-based view*

A Study of the Relationships Between Agility and Sustainability in the Oil and Gas Industry

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Numerous studies have explored the roles, drivers and antecedents of agility and sustainability practices. But, agility and sustainability have rarely been looked at together. As such, there is insufficient investigation and clarity on the influence of the aggregate set of these practices on organisational performance. In addition, the impacts of agile practices on financial measures and strategic operations performance objectives have now been established beyond contention. However, the effects of agile practices on sustainability performance measures require examination and clarification especially given the wider diffusion of agility and the increasing embrace of sustainability. More importantly, the role agility plays in enhancing or not enhancing sustainability is not fully understood. Therefore, this study explored the potential influence of agile practices on sustainability performance criteria. This is significant given that sustainability performance has now become a de facto competitive objective. A preliminary analysis of our data was carried out using a pilot study survey by questionnaire sample of (N = 74) from oil and gas supply chain in the UK. The results suggest a strong and significant correlation between agile practices and sustainability performance measures ($r = 0.547$, $p < 0.000$), the strength of the correlations was the same to that obtained using multivariate regression ($p < 0.000$). Similarly, the correlation between sustainable supply chain practices and competitive performance indicates strong and significant relationship ($r = 0.411$, $p < 0.000$). Whilst previous studies appeared to suggest that sustainability practices have strong positive effects on organisational performance, the findings of this study indicate that there is no strong interconnectedness between them, and at best, the relationship is only moderately positive ($r = 0.307$, $p < 0.008$). The relationship was further examined using multiple regression analysis, which yielded insignificant effects ($p < 0.075$). These findings seem to question the usefulness of implementing sustainability practices within the supply chains when they lack sufficient agility capabilities and equally suggest that agility capability is a neccassary condition for maximal implementation of sustainability and optimal translation into competitive objectives.

Comparison of Wait Time Approximations in Distribution Networks Using (R,Q)-order Policies

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We compare different approximations for the wait time in distribution networks, in which all warehouses use an (R,Q)-order policy. Reporting on the results of extensive computational experiments, we evaluate the quality of several approximations presented in the literature. In these experiments, we used a simulation framework that was set-up to replicate the behavior of the material flow in a real distribution network rather than to comply with the assumptions made in the literature for the different approximation. First, we used random demand data to analyze which approximation works best under which conditions. In a second step, we then checked if the results obtained for random data can be confirmed also for real-world demand data from our industrial partner. Eventually, we derive some guidelines which shall help practitioners to select approximations which are suited well for their application. Still, our results recommend further testing with the actual application's data to verify if a chosen wait time approximation is indeed appropriate in a specific application setting.

Empirical Validity of Inventory Models

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We present a methodology that has been extensively used in practice to develop, test, and implement inventory management models. We distinguish between data acquisition, data cleansing, modelling, verification, validation, and implementation. We introduce the concepts of intervention-independent and intervention –dependent performance indicators and explain their role in the verification and validation phase, and their role when inventory management models are used in daily practice. We discuss a number of case studies that lead to a number of do's and don'ts in applying inventory models in practice.

Heterogeneity of Ordering Behavior in Non-standard Newsvendor Models: Theory and Empirical Findings

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Objectives of study: For the single period newsvendor model in experiments, the so-called pull-to-center (PtC) effect has been observed at an aggregate level, i.e. for a high-profit (low-profit) product the average order quantity of the participating individuals is lower (higher) than the expected profit maximizing quantity. At the individual level, however, the results of experiments showed heterogeneity of ordering behavior: for a specific product some individuals show the PtC effect whereas others order outside the PtC range. Moreover, a group of individuals exhibits the PtC effect for both high-profit and low-profit products. Our aim is to discuss heterogeneity in ordering behavior of two well-known non-standard newsvendor models theoretically and empirically.

Materials and methods: To predict actual ordering behavior we consider a newsvendor model with non-standard preferences with different psychological costs of underordering and overordering where the reference point is the realized demand. In addition, we analyze a newsvendor model with non-standard beliefs: the overconfident newsvendor model (smaller demand variance) is generalized by allowing also underconfidence (higher demand variance). We provide theoretical analyses of the models and empirical findings from a newsvendor experiment done with Bachelor students in production management at WU Vienna.

Results: First, we show that these non-standard newsvendor models fulfill both heterogeneity criteria of ordering behavior and can exhibit the PtC effect at the aggregated level. With the experimental results, we are then able to empirically investigate the actual heterogeneity of ordering behavior at an individual level.

Conclusions: Our results confirm that a reference dependent newsvendor model with different psychological costs of underordering and overordering as well as an extended overconfident newsvendor model including underconfidence can explain the actual ordering behavior of newsvendors.

Keywords: *newsvendor, pull-to-center effect, heterogeneity, experiments*

Quantifying Economic Impact of Classical Forecast Errors in Supply Chain Management

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Traditionally, and more recently, both practitioners and researchers have always been, and there will always be keen interest on the economic effects of forecasting methods on inventory parameters. In this paper, we consider the impact of seven most often used forecasting methods on relevant inventory total cost and inventory variances for replenishment decision characterised by the order up to (OUT) level inventory policy. The demand for this replenishment system is characterised by either a first order auto-regressive, AR(1) process or a mixed first order autoregressive and moving average, ARMA(1,1) process.

The modelling results of the seven key forecasting methods are studied, comparison is made between them, and some practical recommendations are proposed to help practitioners and managers select supreme forecasting method that yields the paramount desired paybacks including:

1. Determination of the costs and benefits of desired service level and fill rate
2. Determination of optimised service level and fill rate
3. Helping them to reduce their inventory costs and inventory variances across the supply chain

Keywords: *Supply chain, inventory costs, inventory control, inventory decisions, forecasting methods*

Inventory and Warehouse Management within Digital Supply Chains

/special session/

Inventory and Warehouse Management within Digital Supply Chains: Opportunities and Challenges

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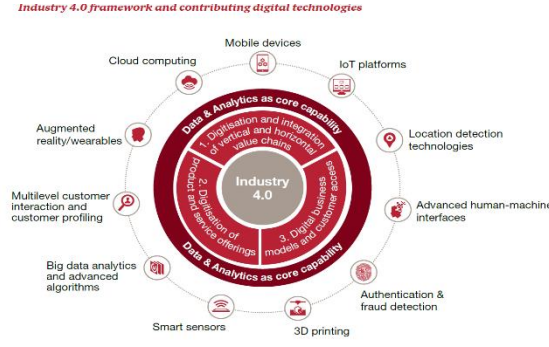
This paper will provide an introductory overview to support the special session discussion and debates. It will deal with the application of the Industry 4.0 leading at advancing digital supply chain supported by SCM 5.0. Applications of Internet of Things (IoT), blockchain and related contemporary technologies alongside applying big data analytics to supply chains and particularly inventory and warehousing management will be reviewed particulary analysisng the positive impact on the inventory and warehousing management management research and practice.

The Industry 4.0 framework presented in figure 1 shows the embedded technologies that are currently applied in logistics and supply chain management leading at digital supply chain transformation. The term Industry 4.0 is related the fourth industrial revolution which is defined as a new level of organization and control over the entire value chain of the life cycle of products; it is geared towards increasingly individualized customer requirements. Industry 4.0 is still visionary but a realistic concept which includes Internet of Things, Industrial Internet, Smart Manufacturing and Cloud based Manufacturing.



The digital supply chain consists of the key elements: integrated planning and execution, logistics visibility, Procurement 4.0, smart warehousing, efficient inventory management, autonomous and B2C logistics, and prescriptive supply chain analytics.

The paper will present a review and current state of the art regarding the following associated topics:

- Digital Supply Chain transformation
- Industry 4.0 driven SCM, inventory and warehousing
- Development and implementation of the smart warehousing solutions
- Using Big data analytics for inventory forecasting and optimisation
- Innovative inventory modelling using analytics

Off-shoring versus On-shoring: A Deep Reinforcement Learning Approach for the Generalized Dual Sourcing Problem

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Problem definition: We optimize the dual sourcing replenishment process of a distribution center, in which a difficult trade-off has to be made between ordering from the regular (off-shore) source with longer lead time and lower cost versus using the express (on-shore) source with shorter lead time but at a premium cost.

Academic/practical relevance: The optimal solution of the dual sourcing problem for non-consecutive lead times (lead time differences between both sources strictly larger than one period) does not have a simple structure and is highly state dependent. Traditional heuristic policies work around this complexity by grouping parts of the inventory pipeline vector and proving (near-)optimal policy parameters, leaving room for methodologies that make better use of the full state of the system. Moreover, strong assumptions such as i.i.d stationary demand and linear transport costs limit implementation in practice.

Methodology: To close these gaps, we model the dual sourcing problem as a Markov Decision Process, and compare three machine learning algorithms based on deep reinforcement learning to solve this analytically intractable problem.

Results: We show how our models compare versus existing heuristic policies in terms of performance in a simple setting. Additionally, we develop an experiment including more realistic constraints such as non-linear transport costs and capacity constraints showing how machine learning can be applied in a more generalized setting.

Managerial insights: Similarly to the way machine learning has improved the level at which games such as the board game Go are being played globally, we show how artificial intelligence can support supply chain managers in their daily decision-making process.

Keywords*: dual sourcing, machine learning, deep reinforcement learning, deep Q-learning (DQN) , Asynchronous Advantage Actor-Critic (A3C)*

Optimal Picker Routing in a Conventional Warehouse with Two Blocks and Arbitrary Start and End Points of a Tour

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Order picking describes the process of retrieving items from storage locations in a warehouse to satisfy customer orders. Even though automating order picking is possible, it is done manually in most warehouses. In manual order picking, warehouse workers often spend a significant amount of their working time on travelling through the warehouse to retrieve requested items. To minimize the time required for retrieving all items contained in an order, researchers have developed various routing procedures that guide the order picker through the warehouse. The paper at hand contributes to this stream of research and proposes an optimal order picker routing policy for a conventional warehouse with two blocks and arbitrary start and end points of a tour. The procedure proposed in this paper extends an earlier work of Löffler et al. (2018) by applying the concepts of Ratliff and Rosenthal (1983) and Roodbergen and de Koster (2001a) that used graph theory and dynamic programming for finding an optimal picker route. The performance of the proposed algorithm is evaluated in an extensive numerical study. Furthermore, we compare the average travel time of the picker in a conventional warehouse with a single block to the case of a conventional warehouse with two blocks to assess the impact of the middle aisle in this context, also taking account of space requirements.

***Keywords**: order picking, picker routing, routing policy, warehousing, picker-to-parts system*

Study on the Customized Products with Consumer's Learning

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In this paper, we study a two-stage problem with consumer's learning setting. In the first stage, the consumers, which maybe myopic, place orders with their preferences on the customized products. Later on, in the second stage, the strategic consumers may want to place orders based on their observations and evaluations of the myopic consumers in the first stage. In short, the orders placed by myopic consumers in the first stage may consider the utility of product customization and product quality. On the other hand, the orders placed by the strategic consumers in the second stage, they may consider not only the utility of product customization level and product quality, but also the learning effects on the observation and evaluations of the first stage consumers.

The Impact of Additive Manufacturing on Inventories – A System Dynamics Based Analysis

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Objectives: Additive Manufacturing (AM) is a layer-based fabrication process for making objects directly from digital design files. Gibson, Rosen and Stucker (2015) list advantages of AM when compared to traditional, subtractive manufacturing techniques such as the capability to build customized and complex shapes, the creation of electronic inventories, parts consolidation, lot size of one and ultimately direct digital manufacturing that lead to disruptive supply chain processes.

The objective of this paper is to study the effects of the adoption of AM on inventories in the manufacturing industry. Internal supply chain processes will be the focus with raw materials-, work in progress- and finished goods inventories.

Methods: For this purpose, a system dynamics model was created for exploratory analysis.

System dynamics is a simulation approach for complex and dynamic systems (Sterman, 2000). The model is based on two main elements. First, the supply chain considering inventories as stocks and transformation rates as flows. Second, a diffusion model according to Bass (1969). These two sub-models were combined to analyze the gradual adoption of AM and its impact on the raw materials-, work in progress- and finished goods inventories measuring average on hand inventory. Modelling parameters were estimated through a literature review and incorporated using Monte Carlo simulation.

Results: The model was validated using various behavior and structure tests. Preliminary results indicate that AM is likely to influence all stages of the manufacturing supply chain but the impact further upstream seems to be bigger. Due to interactions within the supply chain the effect on raw materials inventories might be multiple times higher than on finished goods inventories.

Conclusion: The paper provides good orientation on how AM will impact the manufacturing supply chain and it gives an outlook of the varied effects on inventory levels.

Keywords: *additive manufacturing, 3D printing, direct digital manufacturing, inventory management, system dynamics*

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Maintenance Service Logistics

/special session/

Base-stock Inventory Systems for Service Parts with Service Differentiation and Multiple Batch Demand Classes

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We investigate two inventory systems for service parts under multiple demand classes and service levels differentiation both controlled by base-stock policies. We assume that demands of each class follow a compound Poisson process with random order-sizes and a fixed lead-time common for all classes. We investigate the reservation policy, where a part of the stock is reserved for high priority demand classes. We propose a new threshold policy, where demands of a given class are still admitted until the pipeline stock caused by the particular class plus the amount of the incoming order reaches a critical level. This policy performs better than the reservation policy for low service level of high priority demand classes, low lead-times and homogeneous orders-sizes.

Keywords: *inventory, base-stock, service level, compound Poisson*

Capacity Assignment in Repair Shops under High Material Uncertainty

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We consider a group of identical systems, and each system consists of multiple Line Replaceable Units (LRUs) that fail according to a Poisson process. A failed LRU is replaced by a ready-for-use one from a single stock point and, if not available, a backorder cost is incurred per unit of time. The failed LRU is returned to a repair shop, where it is first inspected and subsequently repaired by replacing one or more Shop Replaceable Units (SRUs) that caused the failure. After completion of the repair job, the failed LRU is ready-for-use again.

Both the ready-for-use LRUs and SRUs are controlled by base stock policies. The repair process is modelled as a two-stage system, i.e. it consists of an inspection and a repair phase. After the inspection phase, the set of SRUs required to start the repair phase is known and the repair job is queued until all required SRUs are available from stock. Once all SRUs are available, the repair job is queued waiting to be repaired.

We introduce two new aspects that are currently not covered in the literature. First, inspection and repair both take a significant amount of time and they are executed by one group of repairmen. Second, repair times depend on the time that elapses between inspection and the actual repair of a part. This raises the question whether priority should be given to inspection of failed parts (to reveal which SRUs are required and speed up sourcing of unavailable SRUs) or to completion of the repair of failed LRUs for which all required SRUs are available (to increase the availability of LRUs).

We model the total repair capacity as a single server and we compare (the total costs for) policies that, based on the repair workload in the repair shop, give priority to either inspection or repair of parts. The total costs consist of inventory holding costs and backordering costs. We take multiple methods to set the SRU base stock levels. Based on simulation, the LRU base stock levels are optimized per capacity priority policy. This leads to a fair comparison of capacity priority policies. We find that generally the repair priority policy performs best.

Keywords: *repairable spare parts, multi-item, two-indenture system, two-stage repair system, priorities, simulation*

Data Analytics for the Pricing of Full-service Maintenance Contracts

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Full-service maintenance contracts are commonly used in the aftersales of heavy equipment. Under such a contract all future costs of (preventive and corrective) maintenance are covered over a predetermined time horizon in exchange for a fixed upfront price. A key challenge is the correct determination of the break-even price of such a contract. In this paper we set out a methodology involving proportional hazards models using customer data to provide insight in the future maintenance costs within a full-service contract. Not only will our approach lead to a correct break-even price, it also leads to a classification of the customer base. This classification may in turn enable price discrimination of future service contracts.

Keywords: *Maintenance, Risk classification, Service contracts, Contract pricing, Price differentiation*

Expediting in Two-Echelon Spare Parts Inventory Systems

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We consider a two-echelon spare parts inventory system consisting of one central warehouse and multiple local warehouses. Each warehouse keeps multiple types of repairable parts to maintain several types of capital goods. The local warehouses face Poisson demand and are replenished by the central warehouse. We assume that unsatisfied demand is backordered at all warehouses. Furthermore, we assume deterministic lead times for the replenishments of the local warehouses. The repair shop at the central warehouse has two repair options for each repairable part: a regular repair option and an expedited repair option. Both repair options have stochastic lead times. Irrespective of the repair option, each repairable part uses a certain resource for its repair. Assuming a dual-index policy at the central warehouse and base stock control at the local warehouses, an exact and efficient evaluation procedure for a given control policy is formulated. To find an optimal control policy, we look at the minimization of total investment costs under constraints on both the aggregate mean number of backorders per capital good type and the aggregate mean fraction of repairs that are expedited per repair resource. For this non-linear non-convex integer programming problem, we develop a greedy heuristic and an algorithm based on decomposition and column generation. Both solution approaches perform very well with average optimality gaps of 1.56 and 0.23 percent, respectively, across a large test bed of industrial size.

Keywords: *inventory, spare parts, multi-item, repair; expediting, multi-echelon, column generation*

Forecasting Spare Part Demand Using Service Maintenance Information

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We focus on the inventory management of critical spare parts that are used for service maintenance. These parts are commonly characterized by a large variety and an intermittent demand pattern. When a service part is required but not immediately available, the incurred shortage costs may be substantial Specialized service parts models should therefore focus on improving the availability of parts whilst limiting the investment in inventories.

We develop a method to forecast the demand of these spare parts by linking it to the service maintenance policy (either preventively or upon failure). As the demand of these parts originates from the maintenance actions that require their use, it is related with the number of machines in the field that make use of this part (known as the installed base), in combination with its failure behaviour and its preventive maintenance policy. By tracking the installed base (through machine sales and discards) and estimating the part failure behaviour, we provide a forecast of the future spare parts demand during the upcoming lead time. This forecast is in turn used to manage inventories.

Our work is validated by a simulation experiment, in which we investigate the trade-off between achieved service level and inventory holdings. We identify part characteristics for which the proposed approach results in an increased service-inventory efficiency compared to traditional forecast methods. We find that we can improve the cycle service level up to 7.5% compared with exponential smoothing, for the same inventory holdings. Moreover, the value of the new method increases when we have more installed base information available.

Keywords: *spare parts, maintenance, forecasting, installed base, service logistics*

Optimal Design of Line Replaceable Units

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We study a company that is responsible for the maintenance of systems and keeps service parts for these systems. When a system stops functioning due to the failure of a part, it is repaired by replacing a maintenance module, which is a collection of parts containing the broken part. Industry refers to such maintenance modules as Line Replaceable Unit (LRU), and we will follow this convention in the remainder. The design of a LRU determines how fast a replacement can be performed, and thus the design of LRUs can reduce the replacement costs. However, the company has to purchase a new LRU to substitute the failed one with. Subsequently, these LRUs are kept on stock and large LRUs are typically more expensive to purchase and to keep on stock. Thus, the objective is to determine the optimal design of LRUs such that the total costs are minimized.

We present a model that captures how various parts in a system are connected, and what disassembly sequences exist, e.g. part A has to be removed before part B. Using this system representation and the assumption that a part belongs to exactly one LRU, we define our optimization model LRU Design that trades off the replacement costs and the purchase and stocking costs. The purchase costs are such that that only the first order effects of stocking the LRUs is incorporated. We prove that LRU Design is NP–Hard, and we present a natural Binary Non–Linear Programming (BNLP) formulation. We linearize this BNLP to obtain a Binary Linear Program (BLP), and we also formulate our problem as a set partitioning problem that allows for branch–and–price algorithms. We prove that the master program, with relaxed integrality, of the set partitioning formulation has an optimal integer solution, and we show that – under very mild conditions – branching is unnecessary; i.e., the problem can be solved by a pure pricing algorithm and yield an optimal integer solution. In our numerical experiments, we numerically compare computation times between the BLP and set partitioning formulation to conclude that only the latter is capable of solving medium to large size instances. Furthermore, we illustrate that complex systems – with many connections between parts and intense disassembly sequences, result in significantly higher total costs. This implies that the OEM should urge his designers to avoid many connections and intense disassembly sequences.

Keywords: *Line Replaceable Units, Binary Linear Programming, Column Generation, Integer Programming*

Practical Repair Shop Priorities

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We focus on technical systems that are used for the primary processes of their users either for producing an end product or delivering service. Examples of such systems are medical equipment, lithography machines, trains, aircraft, and manufacturing equipment. The owners of these systems are concerned with the availability of the system as downtime costs are quite high. Typically upon the failure of the equipment, the defective part is removed and replaced by a ready-for-use part. As the defective part is usually expensive, it is repaired and kept on stock. One of the major decisions that will have remarkable effect on the functionality of the equipment is to decide on the repair priorities of parts. More specifically, the decision maker has to decide on which part to repair first at each decision point while minimizing expected backorder cost. We consider this problem for a repair shop with a single server. In principle, this problem can be solved exactly by dynamic programming. However, it becomes computationally infeasible for many of real life instances. In this study, our aim is to provide methods to compute good prioritization policies tractably for this problem. Notice that the problem is an example for multi-armed bandit problem. We utilize two methods developed in literature to solve restless multi-armed bandit problems for our case, one of which being a heuristic based on a fluid optimization approach and the other being a Whittle's index policy. We derive a closed-form formulation for Whittle's index as a function of steady state probabilities. We test the performance of two methods through numerical simulations.

***Keywords**: Spare parts; Maintenance; Restless multi-armed bandit problem; Whittle's index;*

Spare Parts Inventory Control for Performance-based Contracts

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After the sale of an expensive, technically complex capital good, the OEM typically provides the option to maintain the capital good in exchange for a certain fee. Over the past decades, an increasing focus has arisen on the after sales market due to the vast economic potential and more recently on performance-based contracting. Performance-based contracting intends to link the payment of the service fee with the actual performance of the OEM. For service contracts, performance measures tend to focus on probabilities of fulfilling demand. In some cases, the customer needs to know what will be the maximum waiting time in order to organize some contingency like buffer stock in the case of a serial manufacturing environment. For example, in the semiconductor industry, the costs of a machine being down are in the order of tens of thousands of euros per hour. For such situation, the customer needs to have a certain guarantee that when the system is down, it will be up and running again within a predefined time. This example can easily be generalized to all industries where infrequent long downs have more negative impact than frequent short ones such as serial manufacturers or airlines.

We introduce a new performance measure which limits the number of deliveries that are later than an agreed threshold during the contract execution period. Next to studying this time-based period, we introduce a demand-based period based on realized total demand. We consider a single item, single location stock point serving multiple machines. Using a finite horizon Markov decision process, we define the optimal policy for ordering spare parts based on the actual contract performance for the timebased period. For the demand-based period, the optimal policy is defined using an infinite horizon Markov decision process. For both, our results show that savings can be made when taking into account contract performance in the spare parts ordering decisions. We find that the optimal policies are state-dependent base stock policies, in which the base stock level is non-increasing in the expired duration of the contract and non-increasing in the remaining number of allowed late deliveries. We also show that as the realized failure rate gets higher than the expected failure rate, the total expected cost is lower for our newly introduced contract period definition than the traditional time-based one. For ease of implementation, we develop heuristics to help practitioners implement our findings in practice.

***Keywords**: spare parts inventory, performance measure, Markov Decision Process, optimal policies, heuristic policies*

Spare Parts Management under Double Demand Uncertainty

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When an Original Equipment Manufacturer designs a new capital good and introduces that capital good in the market, a decision has to be taken on the initial stock for the spare parts network. When taking this initial stock decision, an OEM generally has estimates on the expected lifetimes of critical components, and hence on the demand rates at the local warehouses, but these estimates may be highly uncertain. This holds in particular when a new system is designed that is based on new technology. The uncertainty in the failure rates leads to a *double uncertainty* for the inventory problem to be solved: the common uncertainty that one also has under known failure/demand rates and the additional uncertainty because of the uncertainty in these failure/demand rates.

In this paper, we consider the described problem for a setting with a single warehouse and multiple critical items. The items are repairable and each failed item is immediately sent into repair; i.e., there is no batching. Under this rule, the inventory position of each item remains always equal to the initial stock level, to which we also refer as the basestock level. We assume backordering for demands that cannot be met from stock. The aim is to choose the basestock levels for all items such that the relevant costs are minimized while meeting a constraint on the aggregate mean number of backordered demands. The latter measure is directly related to the system availabilities of the machines that are supported.

By exploiting a relation with inventory problems with uncertain leadtimes, we can prove that larger variabilities of the distributions of the demand rates result in higher optimal costs. Next, by numerical experiments, we show how strong the effect is of the uncertainty in the demand rates compared to known demand rates. We will see that one easily gets optimal costs that are 2-4 times the optimal costs under known demand rates. We also show that ignoring the uncertainty in the demand rates leads to solutions that are in general far from feasible and that thus lead to a poor service performance.

Keywords: *Spare parts inventory, uncertain demand rates, multiple items, system-oriented service constraint, stochastic ordering*

Spare Parts Stocking Decisions in Shutdown Planning

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Major process industries shut down periodically to allow maintenance being done to the process units which are normally constantly used. Refineries, for example, may be shut down every 5 years. During such a shutdown time a lot of maintenance needs to be done. Specialised project scheduling is done to keep the time needed for shutdown as short as possible, as every day of downtime invokes high costs. During the shutdown many spare parts are needed in order to allow the maintenance to be done quickly. Accordingly during the year of a shutdown the demand for spare parts is much higher than in years without shutdown. Yet, it also poses the question how to forecast this demand. If replacements are known in advance, then the parts should be ordered in time. Yet in many cases a replacement part is only needed if the condition of the old part is bad. In this contribution we assume that for all relevant parts a probability can be estimated in one or other way of the part being needed in the shutdown. If a part is not present, then ordering it may take some time and delay the maintenance, yet ordering a part and not using it, may lead to excess stocks, which should also be avoided. We will present a project scheduling problem to model this situation with maintenance activities on nodes. The duration of each activity is determined by the probabilistic need for a part as well as their presence. We will present a method, based on stochastic programming to determine which parts to stock and which not and we will evaluate the effect of these part decisions on the project duration. We will compare this stochastic programming method with several heuristics, like the standard one for stochastic activity duration based on a normal distribution.

Stock Rationing in an $M/E_k/1$ Make-to-stock System with Limited-patience Spot Customers

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Motivated by an aerospace service provider, we consider a make-to-stock company's stock ratioining and order decisions. We take into account the real time information on outstanding orders and number of waiting customers from different classes. The company faces two customer classes: (1) contract customers whose demands are practically always accepted and fulfilled, and (2) spot customers who arrive over time and are rejected, satisfied, or put on the waiting list dynamically. The spot customers put on the list may also leave if they have waited too long. We model the problem as an infinite horizon Markov decision process. The supply lead time has an Erlang distribution. Our state space is comprised of the dynamically changing status of the outstanding order, the number of spot customers on the waiting list, as well as the inventory level. The objective is to minimize the total discounted cost. We address the optimality issue of this MDP problem. We also carry out a heuristics policy study, to investigate the value of putting spot customer on the waiting list, and the value of real time information on replenishment orders.

Stockout Risk Estimation and Repair Expediting for Repairable Spare Parts

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Stockouts of repairable spares usually lead to production losses due to downtime of capital products. Hence advance indicators of future stockouts might be crucial for achieving target service levels with reasonable costs since they allow managers to take some actions to avoid backlog cases such as Aircraft-On-Ground in the aviation industry. The most common action against a future repairable stockout is expediting a repair process depending on the difference between regular and expedited repair times. However, frequent usage of repair expediting might create additional workload on a repairshop and top-management of maintenance companies wants to keep the amount of expedited repairable demand under control.

This study consists of two major parts. First, we developed an advance stockout risk estimation method for repairable spare parts. The method considers the number of ongoing repair process and the stochastic customer demand to estimate stockout risk for a repairable spare part for a given planning horizon. In the field tests with empirical data from the aviation industry, the method is found to be accurate for more than 63% of the spare parts for 15 day-planning horizon and the accuracy increases up to 83% when the planning horizon becomes 45 days. Second, we developed a parameter optimization algorithm for the threshold-type policy with two constraints: Minimum service level and maximum expedited demand. The algorithm is proved to be efficient for finding the optimum policy parameter in our tests with empirical data. Both systems are applied in industrial scale and proved to be efficient for repairable spare parts management.

Modelling and Managing Inventories of Perishable Products

/special session/

A Service System with Inventory of Perishable Products and Customers who are Fastidious or Impatient

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We study a Markovian single-server queueing system in which the server utilizes its idle time to accumulate an inventory of pre-prepared perishable products (PPPs) ready for immediate use by future arrivals. The inventoried PPPs are used to reduce the overall sojourn times of customers, but they might spoil and be disposed during storage. Although meeting the required standards, PPPs are perceived as less qualitative compared to services rendered directly. There are two types of customers: fastidious and impatient. A fastidious customer is willing to wait in queue for a fresh product (FP) as long as required, while an arriving impatient customer will take a PPP if the queue size is equal or greater than a certain value m. When PPPs are not available and the queue size is less than M ($\geq m$), impatient customers will wait for an FP; Otherwise, they will leave the system unserved. We analyze the combined queueing-inventory service system and obtain its steady-state probabilities by using matrix geometric methods. Then we show that the service provider, who wishes to maximize his expected profit, can motivate customers to reduce their patience threshold m by giving a discount for each PPP. An interesting result is that by doing so, the service provider not only increases his profit but also increases the average utility of the customers.

An EOQ Model in a Supply Chain of a Perishable Product under a Revenue Sharing Contract

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Consider a two-echelon supply chain consisting of a single manufacturer and a single retailer, who are producing and selling a perishable product. The parties interact by using a revenue sharing contract in which the retailer is the leader. Under this contract, the retailer decides how to split the revenue between the parties, and then the manufacturer sets the product's selling price. Demand is affected by three factors: the selling price, the investment rate in sales effort, and the age of the product. Four cost components are considered: holding cost, production cost, investment in sales effort, and fixed order costs. The holding cost is paid by the retailer, the unit production cost is paid by the manufacturer, and the investment in sales effort can be made either by the manufacturer or by the retailer. The manufacturer and the retailer apply an EOQ ordering regime, according to which, an order of fixed size is made every fixed time interval. Different scenarios regarding decision right allocation and competition are investigated. For each scenario, equilibrium is obtained by applying a game approach.

Discrete Multiple Pricing Policy and Inventory Control for Perishables under Price Dependent Stochastic Demand

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Perishables, such as food, medications, blood products and organs require an effective management due to their limited lifetime. Approximately billions of dollars of food are wasted every month along the whole food supply chain (Minner, 2010). The most common causes for disposing of perishables by retailers are overstocking and inaccurate demand forecasting. In this regard, the selling price plays a crucial role in determining demand, since most consumers have predetermined standards of price versus quality. In this study, we show that a discrete pricing policy with an appropriate inventory management and disposal decisions improves both profit and waste.

The literature considering pricing and inventory decisions for perishable products mainly assumes a single price over the planning horizon (Sana, 2010) or discounts for old items (Buisman, 2017). Kaya (2017) classified the few studies dealing with multiple pricing in two categories. In the first one, the price can vary continuously over time (see e.g. Abed, 1996). In the second one, prices can change according to discrete times (see e.g. Transchel, 2009). In practice, it is not often possible to change prices continuously. This is a limit of the first category of contributions. Therefore, we intend to extend the models allowing for multiple discrete pricing policies. This is in line with Kaya (2017) who assumes that timing of price changes is an important factor that significantly affects the revenues.

Disposal decisions have a significant impact on revenues. In fact, under FIFO issuance policy a suitable disposal strategy reduces the average costs when pricing decisions penalized old items (Haijema, 2014). Thus, it is crucial for the retailer to decide whether to dispose of the old products and replace them with new ones, in order to increase the demand and improve the revenues.

The optimal replenishment, disposal, and pricing strategy under multiple discrete prices for perishable items are unknown for stochastic demand. In this work, we focus on the unified model studied in Chen (2014) considering the stochastic coordinated inventory, pricing and disposal decisions with positive lead-time and lost-sales. The seller has to manage an inventory of perishable products in a periodic-review system. For each period, the retailer decides how much to order and sets a single price for inventories of different ages. At the end of each period, the retailer chooses how much ending inventory to dispose of, including the old inventory in this period and possibly, some of the old items yet to expire. The objective is to maximize the total expected profit above the planning horizon with regard to ordering cost,

inventory holding and lost-sales costs as well as disposal cost. The demand in each period is stochastic and price dependent.

The problem is very complex even when prices are static. Thus, Chen (2014) develop heuristic policies optimizing the selling prices for the entire time horizon and does not consider different timings of price changes. However, we adopt a discrete pricing strategy, giving the ability for a seller to change the prices multiple times over the planning horizon at any time he wants according to the availability of inventory, the remaining shelf lives and the demand behavior. Therefore, we begin with developing a mathematical model to optimize the problem in a deterministic setting. Then, in order to model the real stochastic behavior of demand while dealing with the complexity of the problem, we developed a simulation-based optimization model (SBO-model). Incidentally, we coupled a simulation model, based on the Arena language with the optimizer, Optquest, for solving the problem. We first validated this SBO-model on deterministic instances studied in Chen (2014). We show that we can reach the optimal solution found through the mathematical formulation implemented in CPLEX. Then, we investigate the capability of our SBO-model to solve the stochastic problem.

Through numerical experiments, we compare the multiple pricing strategy with the pricing cases studied by Chen (2014). We observe that discrete pricing outperforms other pricing policies in terms of profit and waste. In fact, the difference of profits between the two pricing strategies is about 20% on average. Moreover, discrete pricing decisions decrease the wasted quantity by 56% on average.

We additionally analyze the effect of the discrete pricing policy we propose in case disposal of yet to expire product is not allowed. We compare this policy to a static pricing policy with disposal and we derive insights on the sustainability of both policies.

Keywords: *Inventory management, discrete pricing, disposal decisions, price dependent stochastic demand, simulation-based optimization*

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Evaluation of Investments in Cold Supply Chains having Final Node in Smart Home

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Cold Supply Chain Management requires more intelligent technology to improve postharvest loss prevention; however, the current technology has to be improved to reduce lead times and perishability dynamics in an intelligent supply chain. This can be achieved by developing a broader and more accurate environmental monitoring and information and communication technology. At the sensory level, control of temperature is studied to be complemented by humidity measurements and nanoparticle sensors which would allow a more direct insight into rotting or decaying during the logistic processes and faster feedback control. By adding constant monitoring of all these measured parameters and enabling their real-time access through cloud computing, the cold supply chain would allow real-time decision making and management. Products exposed to risk need to have opportunity to be sold in nearest market at lower price. Activation of cities for selling products exposed to risk locally is easier if the city is including in CSC communication system. This paper presents a possibility on how to measure the impact of these technologies on the management of cold supply chains in the whole range from packaging, warehousing to distribution and disposal of waste when the fina destination is a smart refrigerator at home. The evaluation of these new technologies is proposed through Net Present Value approach of extended material requirements planning models. An interdisciplinary perspective of industrial engineering and management demonstrates how the development of creative ideas born in separate research fields can be liaised into innovative design of smart control devices and their installation in trucks and warehouses. The paper discusses on how these innovative technologies could contribute to an increase in the net present value of activities in the supply chains of perishable goods in general.

Keywords*: supply chain control; nanosensors; accurate environment monitoring; humidity monitoring, time delay; perishability; postharvest loss prevention, Extended MRP model*

Exploiting Product Substitution in Replenishment to Reduce Food Waste

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Retailers offer large assortments of fresh (packed) products. Some products are substitute to another product but not necessarily the other way around and maybe not to all consumers. In this paper we investigate whether retail profit and waste can be improved by exploiting the willingness of consumers to substitute.

We focus on two products with a short shelf life of three or five periods.

Retail replenishment decisions are modelled by a policy with order-up-to -levels for each product. Profit maximizing values of the order-up-to levels can be obtained by simulation based optimization, using a model that describes the interaction between the inventory levels of both products. As such an approach is much more complex and time consuming than a single product model, order-up-to levels are traditionally set independent of each other.

In this paper we investigate how much profit can be gained when order-up-to levels are optimized simultaneously while taking product substitution into account. It is shown by simulation that in many settings (of pure FIFO withdrawal or a mix FIFO and LIFO) both product waste and profit may increase. We show that product waste can be reduced greatly without jeopardizing profit levels.

In addition, we present an efficient heuristic search procedure that finds optimal order up to levels for both products without too much additional effort.

Inventory and Marketing Policy in a Supply Chain of a Perishable Product under a Wholesale Price Contract

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We investigate a two-echelon supply chain comprising a manufacturer and a retailer, who are negotiating a wholesale price contract for a perishable product. The manufacturer sets the wholesale price, whereas the retailer sets her margin, which together dictate the selling price. Product demand depends on the selling price, the investment rate in sales effort, and the time a unit spends on the shelf before being sold. Four cost components are considered: holding cost, production cost, investment in sales effort, and fixed order costs. The holding cost is paid by the retailer, the unit production cost is paid by the manufacturer, and the investment in sales effort can be made either by the manufacturer or by the retailer. The manufacturer and the retailer apply an economic order quantity policy, where the cycle length is being set endogenously either in a cooperative manner or in a competitive manner. Different power balances between the parties and their effect on the supply chain measures are investigated. In particular, we analyze three cases: manufacturer leader, retailer leader and a bargaining model. For each one, equilibrium is obtained by applying a game approach, and the results are compared with those of a centralized supply chain, which is used as a benchmark.

Pricing and Investment Policy for Agricultural Products with Brand Quality Learning

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In China, accompanied by the rapid development of people's living standard, common agricultural products which show increasing phenomenon of homogenization cannot meet increasing demand, and the construction of agricultural products' brand is urgent. Since brand quality is invisible, customers are gradually familiar with it due to learning effect. This paper considers an inventory model where demand is simultaneously affected by products' selling price, brand quality and external quality. Products' brand quality is affected by joint investment between suppliers and retailers, and customers' learning effect, while external quality is affected by deterioration rate. This paper determines optimal selling price, and investment by maximizing profit in a sales cycle, and analyzes the impact of learning on above optimal decision variables and profit.

Keywords: *Pricing; Agricultural products' brand; Learning effect; Investment*

The Impact of "Minimum Life on Receipt" (MLOR) Agreements on Perishable Product Supply Chains

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In fresh-food supply chains manufacturers strive to supply retailers with products having the maximum remaining shelf life. Specific requirements for product freshness are very often negotiated via ``Minimum life on receipt" (MLOR) criteria that are key components in contracts between retailers and food manufacturers and specify the minimum product shelf life that the retailer is willing to accept. Surveys have shown that many retailers require an MLOR of 85%; however, the actual numbers range from low 40s to high 90s percentages. It is quite intuitive that retailers push for a higher MLOR to reduce waste and cost. For manufacturers, however, a higher MLOR induces increasing pressure on internal operations as the service level agreement (also contractually agreed) is normally rather high. This, in turn, may lead to a suboptimal performance (profit and waste) for the entire supply chain.

In the perishable-product inventory control literature the majority of papers examine single-stage systems, where, for example, a retailer places orders with an external supplier. There is very little research done that investigates contractual issues between decentralized firms managing perishable products and their implication on inventory, ordering, and production decisions in the entire supply chain (Karaesmen et al., 2011).

We study a simplified two-stage supply chain selling a perishable product with a maximum life time of N periods and examine the impact of MLOR agreements on the individual profits and waste of the both retailer and the food manufacturer, as well as on the profitability and waste of the entire supply chain. We use a combination of stochastic modeling and simulation. We derive the optimal replenishment and manufacturing policy for the retailer and the manufacturer. We further compare the decentralized solution with the inventory policy of a

centralized decision-maker, for which we develop a novel approach determining the optimal inventory policy for a general case of a product with a shelf life of N>2 periods and positive lead time.

Our results reveal that MLOR criteria have a significant effect not only on the profitability of supply chains but also waste. Forcing the highest freshness level at the retailer is not necessarily in the best interest for the entire supply chain. We show that the supply chain (both profit and waste) could benefit from MLOR agreements that provide more shelf life flexibility to the manufacturer.

Keywords: *Perishable Products, Inventory Control, Supply Chain Contracting, Stochastic Modeling, Simulation*

Vulnerabilities in Supply Chains for Food and Perishable Products: Identification and Remedies

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Supply chains for food and fresh products have increased in complexity in the recent years because of globalization, shift to industrialized processing and modifications of customer requirements (Teller et al., 2018). Additionally, the specific aspects of perishable products impose supply chain practices, especially, to ensure their quality and safety levels when they reach the consumer. Therefore, the identification of vulnerabilities in supply chain is important. Supply chain vulnerability can be defined as "the propensity of risk sources and risk drivers to outweigh risk mitigating strategies, thus causing adverse supply chain consequences" (Juttner et al., 2003).

Unintentional and intentional food contamination refer to the pollution of the product by an undesirable biological, chemical, physical or radiological substance during the production, transport, storage or distribution phases. The causes can range from the improper supply chain design, supply chain management shortcomings (transport and lead time issues, inventory replenishment, etc.) and infringement to the procedures and regulations to natural as well as man-made (criminal, terrorist attacks, etc.) disasters .

The consequences of such vulnerabilities on individuals, companies, society, country or at a regional level include health threats, deaths, financial losses, compromised reputation, food waste and food security issues.

In this paper, we examine some of the most recent food contamination cases to develop a dynamic model for vulnerabilities in supply chains for food and perishable products. This model will be used to identify the breaches, evaluate the existing rules, regulations and practices and to evaluate recommendations for supply chain design as well as supply chain management.

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Teaching Inventory Management and Control

/special session/

Building Integrator-Skills in Supply Chain and Operations Management Study Programs

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As an academic education discipline, the supply chain and operations management (SCM/OM) has core substance knowledge that is composed of key concepts, theories and techniques. These include production planning and control, inventory management and control, supply chain design and management, as well as service operations management. However, modern business world requires, as an addition to substance knowledge, an extensive set of more practical and generic skills from graduates. SCM/OM experts work usually as a business process developers. This integrating role between different organizational functions and networks requires a wide set of skills. These skills (named here the integrator-skills) include among other things: ability to comprehend complicated cause-effect relationships, ability to analyze improvement opportunities and challenges, ability to create improvement solutions and recommendations for decision-making, as well as apply methods and implement changes in organizational improvement teams and projects. Integrator-skills are essential and built-in requirements in carrying out supply chain and operations management expert and managerial work tasks. Hence, they should be an integral part in learning outcomes of SCM/OM educational programs and curriculums.

This paper presents and analyze a Supply Chain and Operations Management study program. The presented program is designed based on the recognized need for more comprehensive skill set for students. The program aim to include integrator-skills to all levels and aspects in SCM/OM academic education. The aim in the presentation and analysis is to describe how the integrator-skills can be advanced together with SCM/OM expertise systematically and step-by-step throughout the whole education process. The focus is in:

- Student-teacher interaction: how the change teaching towards participatory and activating methods and techniques?
- Comprehensive case assignments: how to use large and complex assignments in simulating real experiences and facilitating problem-based-learning?
- Assessment methods: how to integrate assessment and teaching methods to improve continuous learning-by-doing?

As an addition, the ways how the needed skills can be recognized as a basis for developing study programs are discussed. Future improvement need in teaching integrator-skills for SCM/OM students are concluded based on the analyzed study program.

Teaching Inventory Optimization In 11 Class Sessions

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This talk describes how I teach inventory optimization in a half-semester course. For the past three years, I have taught the course at the University of Tennessee Knoxville and taught, or co-taught, the course at MIT. Prior to 2015, I taught the course many times at Boston University to both graduate and undergraduate students.

The audience for the course is extremely broad, drawing on students from engineering, business, and specialized programs in analytics, data science, executive education, manufacturing engineering, and supply chain. Some of the students are very sophisticated mathematically while others remember little from their last math course taken in secondary school. Some of the students have had operational responsibilities managing hundreds of people while others have never worked. Some students have taken a one-semester core operations management course but for most of the students this is the first, and likely only, course they will take from an operations management faculty member during their program.

The course is comprised of eight cases and three lectures. The course is case driven from a MIT perspective. Students are taught the basic mathematical model required to provide a baseline answer to the case. The students are then responsible for extending that model to create a better solution (where better is defined as more closely meeting the decision maker's objective). Prior to the case discussion in class, the students are given little direction on how to enhance the basic model; the expectation is we will work through several of the suggested enhancements in class, better understand the positives and negatives of each approach as well as the technical merits of the approach, and then carefully step through at least one of the advanced solutions. The benefit of this class format is it establishes a baseline level of knowledge for each student, but it also gives them the opportunity to better understand the art and science of inventory problem solving.

There are two significant innovations in the course. First, all the cases are written with former students that have taken the course. This reinforces the core learning in the course that "simple" models apply in practice. Second, the structure of the course lets students learn why inventory optimization is hard. This is a gradual experiential process, that takes most of the course to accomplish. My talk will go into the format in much more detail, as well as the learnings associated with each class.

Keywords: *Base stock modeling, forecasting, multiechelon inventory optimization, newsvendor modeling, service level optimization,*

Best Student Paper Award Finalists

A Newsvendor Framework for Sustainable Sourcing Including Capacity Reservation for Recycled Materials

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Objectives of study: We discuss how the integration of recycling material into the sourcing strategy impacts a manufacturer's economic and environmental performance. We therefore model a sustainable sourcing strategy of a manufacturer operating in a dual sourcing environment with one proactive supplier (a contract supplier) delivering recycled material with uncertain yield (due to issues in the recycling process the delivered quantity of the recycler to the manufacturer does not necessarily equal the reservation quantity) and a second reactive supplier delivering virgin material at an uncertain price reflecting the price volatility at the spot market. We consider a quantity reservation contract with an uncertain exercise price. The manufacturer's decision on capacity reservation has to reflect the uncertainties associated with the sourcing process as well as potential dependencies between them. The goal is to get insights on such a sustainable sourcing strategy.

Materials and methods: We develop a single-period inventory model with procurement from a supplier offering recycled material according to a capacity reservation contract and a reactive supplier (spot market) offering virgin material. We consider uncertainties of demand, prices and recycling quantities as well as potential dependencies between them, in particular the dependencies between prices for virgin and recycled materials and prices and demand.

Results: We provide results on the optimal policy structure and obtain a closed form solution as a bound of the optimal procurement quantity. It gives us first insights on the effect of different economic parameters on the ordering decision. In an extensive numerical analysis we then study the impact of correlation on our results in order to derive managerial implications. We show that considering correlation when using such a sourcing strategy is especially important in environments with high demand uncertainty, high virgin material prices and yield uncertainty. Moreover, implementing a sustainable sourcing strategy contributes to the concept of circular economy as the input of virgin material can be (partly) replaced by recycling material.

Conclusions: We provide managerial insights in the economic and environmental benefits of sustainable sourcing with recycling that contributes to an increase in sustainability of supply chains.

Keywords: *capacity reservation, newsvendor, multiple sourcing, recycling, sustainability*

Competitive Inventory Rebalancing with Application to Car-Sharing

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While inventory based competition and inventory rebalancing by themselves have been studied very well, rebalancing under competition has not been addressed directly so far: All game-theoretic approaches for transshipment problems assume that the players pool their remaining inventory. We propose a method for determining the optimal rebalancing under inventory competition for a given pool of stock. That is, we consider two players who compete with a substitutable product at several locations. As customers are willing to substitute, the players' inventory levels mutually influence each other's demand expectations. Consequently, the players have to find the most profitable redistribution of their inventory among the locations while taking into account the competitor's reaction.

We first study the rebalancing problem without competition. By aid of Lagrangian multipliers, the locations can be partitioned into sending, dormant and receiving ones. This allows us to develop an efficient algorithm that determines the optimal solution from the Lagrangian multipliers without explicitly solving the optimization problem. In a next step, we consider a non-cooperative Nash game, where both players solve the rebalancing problem simultaneously. To cover different customer behaviour, we consider the problem under stock-out-based as well as availability-based substitution. We prove that there exist unique Nash equilibria for both cases of customer substitution.

Our controlled numerical design shows that the initial distribution of the inventory is the main driver for an increase or decrease in the number of rebalanced units. If one player initially dominates a location, the competitor will focus on serving the player's unserved demand in the other location. In contrast, when both players have few units at a location, the number of moved units increases substantially.

A real-world application to the competitive rebalancing is the case of car-sharing. A case study with real booking data from Munich shows that ignoring the presence of a competitor can come at a high cost. That is, the players could increase their profits in Munich by up to 1.7 million EUR per year if they adapt to the competitive environment. Thanks to substitution, the β-service-level would increase by up to five percent. Furthermore, we show that a joint rebalancing could increase the profits by seventeen percent per annum and the number of repositioned cars would decrease by more than twenty percent.

Keywords: *rebalancing, competition, Nash equilibrium, substitution, car-sharing*

Printing Spare Parts at Remote Locations: Fulfilling the Promise of Additive Manufacturing

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We investigate the benefits of on-site printing of spare parts at remote geographical locations. We consider a periodic-review spare part inventory control system with two supply sources. Replenishment of regular spare parts occurs according to a fixed time interval. In between replenishments, shortages of spare parts can be met by printing a spare part that possesses a lower reliability than the regular part. We characterize the optimal inventory control policy and we conduct experiments to investigate the benefit of on-site printing. Two case studies, which have been conducted with the Royal Netherlands Army, are presented to illustrate how general-purpose AM technology for on-site printing can create significant benefits. We further present two extensions to our model. Our results show that remote locations are a prime candidate for implementing AM technology to print spare parts on-site and on-demand.

In-Absentia

Authentically Recorded Manual Interventions in IT Supported Inventory Management Systems

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Elaborating properly organized and transparent business procedures is a key for achieving the corporate strategic goals and the cost-efficient operation. In the course of regular operations executing is not always conform to the rules stipulated for the particular procedure. Primary sources of the operation differing from the normal one are the steps of the workflow requiring human intervention. Those manual steps cannot be eliminated by means of IT systems supporting business procedures so far and on the long run either.

For the sake of amending the faults emerged during the execution of the procedures and clarifying the responsibilities said manual interventions shall be documented. The corporate IT solutions supporting procedures typically deal with the normal execution of workflows, and frequently set aside dealing with irregular cases. Documenting authentically said cases is typically cumbersome. By creating the Electronic Minutes Management System, we had the goal to make possible quick and simple electronic saving of cases requiring authentication, the related transparent registry and to follow-up the troubleshooting steps. The EMM System is particularly suited to support the inventory management process from the point of view of property protection. By integrating the EMM system into a stock management process, it is ensured that the product or material which could be damaged by packaging, delivery or loading, can not be deposited in the warehouse. The result is preventing the entire supply chain from being damaged or by selling unsatisfactory quality. Insufficient quality may be compromised company's reputation, business position and profitability. According to statistics, the availability of human mistakes is relatively high in inventory processes, but the definition of responsibilities is rather difficult. EMM system is possible to prevent the effective decisions causing the damage and preventing misuse. The result is a quick reaction to the determination of material and moral responsibilities. The authentic documentation attached to the rules, prepared by the EMM System, is able to quickly start to handle problems by means of the appropriate escalating path depending on the detected problem, deviations. The client components adapted to mobile devices facilitate ergonomic and easy use in the course of each phase, thus facilitating a well-transparent and regulated operation, which encourages employees to work responsibly, raising the cost-effectiveness of the company.

Keywords: *property protection, optimization, responsibility, statistics, inventory management processes*

Coordinating the Decentralized Supply Chain under a Guaranteed Service Model

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Real world supply chains involve complex multi- echelon systems for which it is not straightforward to allocate safety stocks for each echelon under external demand uncertainty. To solve such a problem, the research community propose the Stochastic Model (SM) and the Guaranteed- Service Model (GSM) approaches. Hwarng et al. (2005) point out that the related research on the SM approach mostly focuses on two-echelon distribution systems since the SM approach becomes computationally intractable for more complex systems. However, real-world supply chains are usually composed of several echelons and represent a general multi-echelon system.

In a multi-echelon inventory system, the Guaranteed-Service (GS) Model (GSM) aims at determining the optimal placement and amount of safety stocks that ensures a target service level at the lowest cost (Graves and Willems (2003)). This model assumes that demand is bounded at each stage of the considered supply chain where demand bounds are usually obtained on the basis of a target Cycle-Service-Level (CSL).

In this paper, we aim to illustrate how to use GSM in a decentralized supply chain controlled by different parties which could represents different firms or different business units with separate key performance indicators. Particularly, we investigate how the guaranteed-service could be firstly strategically set by the different supply chain decision makers. Then, secondly how the chosen GS could be used in a multi-echelon safety stock calculation. We develop three scenarios where in the first one, a unique decision maker aims to optimize the performance globally for the supply chain. In the second scenario, GS are chosen separately by the different decision makers and associated inventory control parameters are deduced. In the third scenario, we propose a contract structure that codifies the GS relationship, and elaborate that in addition to supply chain coordination, this form of cooperation is compatible with many properties which are defined as "desirable for coordination" in the investigation of Lee and Whang (1999).

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Do the Structural Hole States Affect the Network Rent within Triadic Supply Chains? The Manufacturer's Perspective

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With increasingly complex relationships among companies, the concept of triads becomes an essential tool for investigating the structure of contemporary supply chains. Within the triadic arrangements, one may identify a 'structural hole' defined as a gap, occupied by a specific company and positioned between two disconnected actors in a triad. In our study we consider the manufacturer sitting on the structural hole, who is capable of establishing three basic structural hole states. They are determined by the *so-called* relational posture of dyads ranging from adversarial (negative) to cooperative (positive). The goal of the paper is twofold. First, we aim to explore the ability of the manufacturer to achieve the network rent, which is modeled as the outcome of joint-effect between the relational performances of two dyads (supplier-manufacturer and manufacturer-customer) within triads. Secondly, we seek to recognize how the structural hole states, shaped by the manufacturer, affect the network rent in triads. The findings of our research demonstrate that the network rent is yielded in the investigated triads; however, its value, as evidenced in our study, is dependent upon the specific structural hole state. More specifically, the highest value of rent is generated by triads with cooperative posture of both dyads, whereas the value of rent close to zero is revealed in triads with negative relational posture of both dyads. Interestingly, the lowest level of network rent is reported by a hybrid type of arrangement, in which one dyad demonstrates a more cooperative relational posture, whereas the other one indicates an adversarial relational posture. The obtained result not only suggests that there is no rent, but it goes further to indicate a negative return (or loss) derived by the manufacturer in this group of triads.

Identifying Inventory Management Conflicts: Results of an Empirical Study

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Both in theory and in practice it is widely acknowledged that due to their multidimensional character, implementing inventory systems can be a complex and dynamic process. Projects in the area of inventory management for instance, are often linked to multiple business processes like sales, planning and purchasing. Moreover, implementing inventory systems not only includes a technical dimension but an organisational dimension as well. Allocating authorities and responsibilities to staff members as well as creating coordinating mechanisms between the stakeholders involved are some examples of organisational aspects of inventory systems which also heavily influence the performance of inventory systems (e.g. Kisperska-Morron, 2003). It is for this reason that the organisational embedding of inventory systems has recently drawn the attention of scholars Clearly, often many different stakeholders participate in the process of designing and implementing inventory management systems and recent studies indicate that the process of shaping inventory systems rather than a technical process often is a social and political process as well. Projects in the area of inventory systems therefore are frequently characterized by a high degree of dynamics and complexity and often go hand in hand with conflicts and political processes (de Vries, 2013).

Although conflicts are being studied in many different management fields amongst which psychology, marketing and human resource management, there seems to be a rather restricted number of studies on inventory management-related conflicts. Moreover, almost no empirical studies are available regarding the question what the causes of conflicts during the shaping and implementation of inventory systems are. Clearly, the implementation and usage of inventory systems often include organisational issues related to trust, the sharing of information across departmental borders and questions on how to deal with opposing interests of different stakeholders. Previous research in the area of information systems suggests however that conflicts might be rooted in more fundamental principles (Levine e.a., 1994; Boonstra e.a., 2015) and it is for this reason why we conducted a study on exploring the different types of conflicts, their causes and the emerging character of conflicts during the shaping, implementation and usage of inventory systems.

Our full paper draws heavily on five case studies. In doing so, a framework for assessing different types of conflicts is taken as a starting point. Starting from the notion that inventory systems encompass a physical, planning, informational, and organisational dimension, a framework on inventory-related conflicts is presented. This framework is rooted in recent studies on information system conflicts and categorizes inventory management related conflicts in four types. In the second part of the paper,

this framework is used to reveal how different conflicts have influenced the shaping, implementation and usage of different inventory systems. In doing so, empirical data is presented and analysed of five in depth explorative case studies. The last section of the paper elaborates on some of the main findings of the case studies. First of all conclusions are drawn about the different types of conflicts and on how these conflicts have impacted the performance of the inventory systems studied. Secondly, conclusions are drawn on the applicability of the framework. In doing so we see our contribution as a further step in gaining more in depth and systemised knowledge on recognizing and understanding conflicts between stakeholders during the process of shaping, implementing and using inventory systems. Hopefully, this knowledge will enable practitioners to deal with different types of inventory management conflicts more effectively.

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Including Sustainability Criteria into the Multi-Supplier Newsvendor Problem: An MCDM and Bi-Objective Optimization Approach

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We develop a single product single-period inventory control model with stochastic demand, in which a retailer buys, at the beginning of the single-period, a quantity of a perishable product from one or more than one supplier with limited capacity. The end customers' random demand that should be satisfied by the retailer is concentrated in a single period selling season during which every satisfied demand is charged a certain price by the retailer. At the end of the selling season, any remaining units are salvaged by the retailer at a salvage value and any unsatisfied demands incur a penalty shortage cost.

The problem is modeled using a bi-objective optimization framework. First, fuzzy TOPSIS is used in order to measure the closeness coefficients of all the available suppliers based on pre-determined sustainability criteria, that include green ones, such as the geographical distance between the production site of the supplier and the site of the retailer's warehouses, and social criteria such as the impact of the production activities on the local society. AHP is then used in order to determine the importance weights of the green and social penalty shortage and customer satisfaction coefficients. Furthermore, we model two independent multi-supplier newsvendor problems: a cost based sub-problem and a sustainability (green and social) based sub-problem. We solve each of these sub-problems analytically and we exhibit the structure of the optimal policy and therefore the optimal quantity to order from each supplier in both cases. We use then the comprehensive criterion method in order to solve the bi-objective model and we exhibit the structure of its optimal policy and the Pareto optimal solutions.

Furthermore, through a numerical study, we analyze the effect of some of the model parameters on the optimal policy and on the Pareto solutions. More particularly, we investigate the relative weight of the different criteria, the randomness of the demand, the difference in the costs between the supply options and the other economic parameters.

***Keywords**: multi-supplier newsvendor, green and social sustainability, bi-objective optimization, MCDM, short life-cycle products.*

Integrated Manufacturer-Retailer Closed-Loop Inventory System with Price-Sensitive Return and Demand Rates

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This study develops an integrated manufacturer-retailer closed-loop inventory system with price-sensitive return and demand rates. Glass bottles and printer cartridges are examples of products that can be recycled and used as new components. The demand rate is price-sensitive to the selling price, and the return rate depends on the return price of a recycled component. This paper considers four scenarios: (i) with recycling and integration, (ii) with recycling and without integration, (iii) without recycling and with integration, and (iv) without recycling and integration. The purpose of this study is to optimize the product selling price, component return price, lot sizes of new and return components, and the lot size of finished products delivered to the retailer. A numerical example is provided to illustrate the proposed model. Sensitivity analysis on return price, selling price, purchase cost, and other parameters are conducted. In addition, a comparison on the differences between considering and without considering the recycling and/or integration is presented.

***Keywords**: Inventory, recycled component, closed-loop system, price-sensitive demand rate, price-sensitive return rate*

Optimizing a Production-Inventory System Considering the Impact of Production Risk under Decreasing Price/Demand rate Conditions

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With the popularity of 3C (Computer, Communication and Consumer Electronics) products in daily life, the market access to 3C products, the rapid increase in addition to a wave of information exhibition, computer exhibition, the various entities and virtual access to the market quickly. The demand rate and the selling price usually decline at continuous rates. The production schedule of these products is difficult to plan, and may result in production risk (the cost of over or insufficient production). Therefore, there is a need to develop a different production strategy to consider the impact of production risk. In this paper, we consider a production-inventory system with a finite planning horizon with decreasing demand and partial backordering. The total profits for the LIFO (last in first out) and the FIFO (first in first out) backordering policies are compared. A numerical example and sensitivity analysis are carried out to illustrate this model.

Keywords: *Inventory; decreasing demand; production risk; partially backordering*

Temporary Price Increase During Replenishment Leadtime

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Dynamic pricing is the most natural mechanism of revenue management. Firms use various forms of dynamic pricing, including personalized pricing, markdowns, promotions, coupons, discounts and clearance sales, to respond to market fluctuations and demand uncertainty. In this paper, we study a temporary price increase policy for a non-perishable product, a practice used by several giant retailers. Thus, both pricing and inventory decisions need to be made simultaneously: pricing decisions are used to control demand, while inventory replenishment decisions are used to control supply. The price increase is exercised during the replenishment leadtime. The objective is to increase the expected profits by raising sales revenues, while reducing the demand rate to lower the stock-out costs. The problem is therefore how to coordinate the pricing and replenishment decisions, and obtain insights on the benefits of such a policy and its effects on the replenishment decisions. Through extensive numerical and sensitivity analyses, we show that significant improvements in the expected profit obtained when compared to a conventional single price policy.

***Keywords**: pricing, continuous review, lost sales, inventory control, replenishment policy*

Understanding Service Innovation Introduction and Diffusion through the lens of the Economic Order Quantity Model

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Effective management of service operations has received significant attention in extant studies. One aspect of service operations that has received attention within the service operations literature is service innovation. The emphasis on service innovation is due to its perceived impact on the competitiveness of firms through radically new or improved service concepts or processes. Specifically, traditional service innovation literature focuses on introduction of new services, new products and new processes. Unlike tangible manufactured products, services have unique characteristics including the intangibility of services, the simultaneous production and consumption of services and the high level customer contact and involvement in both production and consumption. These unique characteristics motivate the need to understand how service innovations are introduced and how they diffuse or percolate targeted markets. In addition, services vary widely, as such their patterns of diffusion may differ. Specifically, some service innovations may follow the traditional "S" curve product-life-cycle stages comprising introduction, take-off, maturity and decline. While others may not. Indeed, using novel data of daily usage of online game services in South Korea, we find that the demand for service innovations in such online game industry appear to follow the saw-tooth patterns typically observed in the traditional inventory profile model of economic order quantity. We find that at the point of introduction, online games innovation attracts a sudden or sharp and almost vertical jump in performance (or market share measured by the number of users or players) which is akin to the order quantity of the EOQ model. Over time, this level declines down to a particular point (similar to the re-order point) where it experiences another sudden jump when a new service or improvement to the existing offering is introduced. This interesting observation raises a few questions about service innovation in such industries which we attempt to investigate in this study. First, what types of service products or innovations experience this type of introduction and diffusion profile and why? Second, what determines the timing of new service updates or innovation? Or is there an optimal timing of a new service innovation introduction? (similar to the re-order point in the EOQ model)? Third, is there an optimal level of service innovation novelty or innovativeness that drives the usage level (similar to the order quantity level in the EOQ model)?

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