Summary Report of 12th ISIR SUMMER SCHOOL

"Value-Driven Inventory Management in Logistics and Supply Chains New and Classical Streams in Inventory Management"

17th-21st August, 2015

Kuehne Logistics University, Hamburg, Germany

The 12th ISIR summer school was hosted at the Kuehne Logistics University (KLU) in Hamburg, Germany, and was organized by Prof. Sandra Transchel. We had keynotes, tutorials, and presentations by distinguished professors and Ph.D. students on recent research around the central theme "Value-Driven Inventory Management in Logistics and Supply Chains". The variety of research topics, methodologies, and the multitude of nationalities of the participants was outstanding.

In addition to presentations that focused on rather conventional problems of inventory research, such as spare parts management, safety stock calculation, and replenishment frequency optimization, there were also several other interesting talks that presented research which focuses on extended supply chain problems, such as the determination of stocking quantities as function of transportation modes, product allocation in humanitarian operations, or the effects of CEO incentives on inventory levels. Regarding research methodologies, literature reviews, case studies, analytical and empirical methods were presented. Each presentation was followed by a discussion session that was led by a senior researcher and a Ph.D. student. Because all participants had strong common backgrounds in inventory research, each of the discussions was very rich with insights - some discussion were so heated that they continued offline. Exciting excursions and socializing events with a group of more than 10 different nationalities conveyed the unique spirit of Hamburg and provided opportunities for Professors and Ph.D. students to get to know each other.

After the welcoming of the participants, the summer school started its official scientific program, on Monday, 17th of August, with a keynote presentation by Prof. Attila Chickàn from Corvinus University, addressing the issue of "Global trends of national inventory behaviour". In a lively and comprehensive presentation Prof. Chickàn introduced the participants to the different features and importance of inventory investment in various countries. He concluded that the globalization of economic activity has a great impact on national inventory accumulation, leading to rather similar behavior in various countries. The afternoon's keynote by Prof. Henk Zijm from the University of Twente on "Coordination and collaboration in freight logistics" reported a number of projects, at both national and international levels, that have been undertaken in order to address problems in today's logistics and supply chains and to propose smarter logistics and mobility solutions. The presentation ended with a brief discussion

of a long-term vision on future logistics and supply chains: The Physical Internet. On Tuesday 18th, the second day of the summer school, Prof. Mirko Kremer from the Frankfurt School of Finance gave a tutorial on "On the usefulness of (laboratory) experiments in OM research and how to actually pull one off". The aim of the presentation was to introduce laboratory experiments as part of the methodological toolbox of Operations Management researchers that has recently gained huge recognition in academia and to discuss some of the issues regarding the design and conduction of experiments. In the afternoon, Dr. Marcel Sieke gave some useful insights about Barkawi Management Consultants by presenting "Inventory Management – Putting theory into practice". Following Marcel's presentation, a case study competition on "Integrating complex data streams into causal and fact based prediction models" was introduced. The case study, which was led by Barkawi Management Consultants, was based on a real company project with E.ON Connecting Energies GmbH and gave the students the opportunity to collaborate in teams and gain some more practical experience. On Thursday, 20th the last tutorial of this Summer School was given by Prof. Nagesh Gavirneni on "Initiating, conducting, and completing research in operations management: Observations from the past twenty years". By promoting an open discussion between the participants, Professor Nagesh Gavirneni from Cornell University shared his personal opinion regarding these topics, gave helpful advice, and as such inspired the audience to find their own path to good research.

By provision of an ideal platform for people from around the globe, the Summer School proved once again to be extremely valuable beyond mere academic purposes. Amongst others, Tuesday's dinner in the Wasserschloss, a traditional restaurant in the old warehouse district of Hamburg, and Wednesday's visit of the HHLA container terminal, complemented by a harbor cruise on a barge, provided room for fruitful discussions and conversations while at the same time some of the sights in Hamburg were seen. Finally, a joint visit of and bar tour through the famous Reeperbahn in Hamburg's red light district definitely broke the last ice among the participants. We hope everyone enjoyed the Summer School and we look forward to meeting all of you soon again.

12th ISIR Summer School
Hamburg 17.-21. August 2015
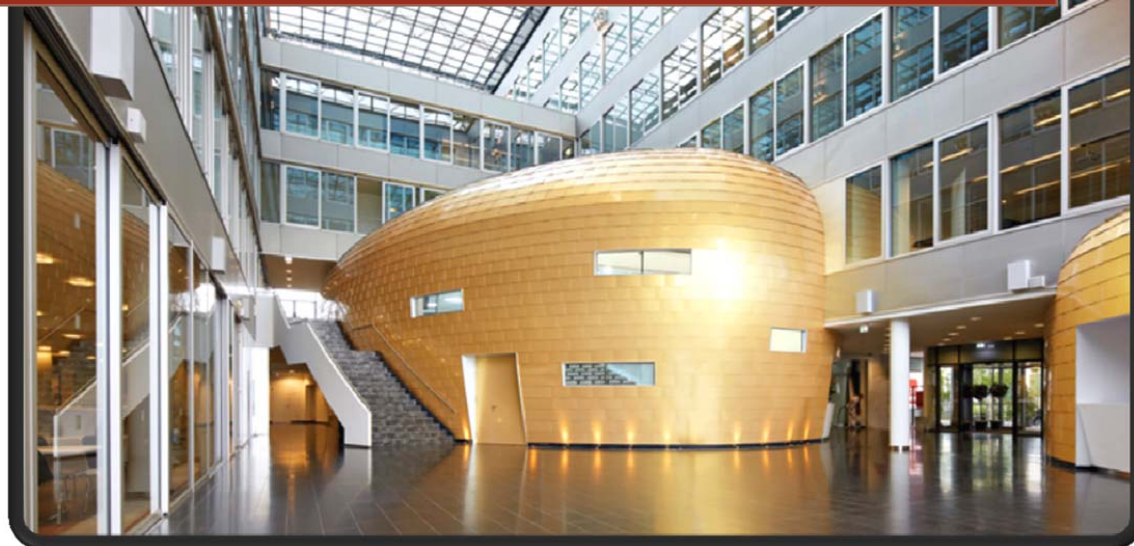
Value-Driven Inventory Management in Logistics and Supply Chains

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Welcome to the Kühne Logistics University

The Kühne Logistics University (KLU) is an independent, state-accredited, private university located in Hamburg's waterfront HafenCity, Germany's gateway to the world and northern Europe's leading logistics metropolis. Sponsored by the nonprofit Kühne-Stiftung, KLU is dedicated to research and teaching in the fields of logistics, supply chain management, management, and economics. The mission of KLU with its study programs and research is to educate and prepare potential future leaders for being able to master challenges within all industries. Students experience logistics and supply chain management as a cross-over discipline which affects many fields of business practice and theory.

KLU is a true international university where an international faculty teaches an international student body. Practice-oriented teaching and research expertise in logistics and corporate management give KLU a unique position in the global market. The Handelsblatt Research Rankings 2014 identified KLU as one of the leading universities in Germany, Austria, and Switzerland with respect to research output per professor. In the 2014 CHE University ranking KLU achieved the highest rating in all major criteria. On its unique campus in close proximity to the port of Hamburg, about 30 professors at KLU will soon be training 500 students in the logistics and corporate management fields for the global market.

Schedule

Monday, August 17, 2015

08:30 – 09:00　　**Registration**

09:00 – 09:15　　**Opening Session**
Attila Chikán, Corvinus University
Sandra Transchel, Kühne Logistics University

09:15 – 10:00　　**KEYNOTE: Global trends of national inventory behavior**
Attila Chikán, Corvinus University

10:00 – 10:45　　**Implications of additive manufacturing for after sales service logistics**
Presenter: Nils Knofius
Discussants: Dennis Prak, Krisztina Demeter

10:45 – 11:15　　**Coffee Break**

11:15 – 12:00　　**Integrated field service engineers and spare parts planning in maintenance logistics**
Presenter: Sajjad Rahimi Ghahroodi
Discussants: Sha Zu, Ou Tang

12:15 – 13:00　　**A model of raw material supply under uncertainty in commodity prices, exchange rates and demand: A case study in the industry of electrical cables & wires**
Presenter: Stephanía Mosquera López
Discussants: Patrizia Rogetzer, Attila Chikán

13:00 – 14:15　　**Lunch Break**

14:15 – 15:00　　**KEYNOTE: Coordination and collaboration in freight logistics**
Henk Zijm, University of Twente and Dutch Institute of Advanced Logistics

15:15 – 16:00　　**Managing different demand classes in a spare parts inventory: A practical dynamic allocation strategy**
Presenter: Erica Pastore
Discussants: Beatrice Marchi, Henk Zijm

16:00 – 16:15   **Coffee Break**

16:15 – 17:00   **An inventory control model for modal split transport: A tailored base-surge approach**
Presenter: Chuanwen Dong
Discussants: Evan Wingerden, Stefan Minner
17:15 – 18:00   **Commodity spot market procurement under hidden markov modulated prices**
Presenter: Christian Mandl
Discussants: Danja Sonntag, Nagesh Gavirneni

18:00 – 20:00   **WELCOME RECEPTION**
Faculty Lounge – 4th floor

Tuesday, August 18, 2015

09:00 – 09:45   **On the calculation of safety stocks**
Presenter: Dennis Prak
Discussants: Sajjad Rahimi Ghahroodi, Mirko Kremer
10:00 – 10:45   **The impact of real time yield information on the safety stock in a multistage serial   production system**
Presenter: Danja Sonntag
Discussants: Mervegül Kirci, Nagesh Gavirneni

10:45 – 11:15   **Coffee Break**

11:15 – 12:45   **TUTORIAL: On the usefulness of (laboratory) experiments in OM research. And how to actually pull one off**
Mirko Kremer, Frankfurt School of Finance

12:45 – 14:00   **Lunch Break**

14:00 – 14:45   **You get what you pay for:**
CEO compensation and the inventory rhombus
Presenter: Kristoph Ullrich
Discussants: Nils Knofius, Mirko Kremer

14:45 – 15:30   **KEYNOTE: Inventory Management - Putting Theory Into Practice**
Presenter: Dr. Marcel Sieke, Principal at Barkawi Management Consultants

15:30 – 15:45   **Coffee Break**

15:45 – 19:00   <u>CASE STUDY</u>: Integrating complex data streams into causal and fact based prediction models (Barkawi Management Consultants)

19:30 – 22:00   **Summer School Dinner**
Wasserschloss , Hafencity

Wednesday, August 19, 2015

09:00 – 11:00   <u>CASE STUDY</u>: **Presentations**

11:00 – 11:15   **Coffee Break**

11:15 – 12:00   **Cash & voucher programs in humanitarian operations**
Presenter: Christos Bitos
Discussants: Naoum Tsolakis, Peter Kelle

12:00 – 13:00   **Lunch Break**

13:00 – 16:00   *Company visit – HHLA Hamburger Hafen und Logistik AG (Container Terminal Altenwerder)*
13:00   Departure at KLU
14:00 – 15:00   visit HHLA
15:00   Departure at HHLA to Pier „Elbphilharmonie"

16:00 – 18:30   *Harbour cruise on the barge „NAKU"*

18:30   End of the tour at the pier "Elbphilharmonie"

Thursday, August 20, 2015

09:00 – 09:45 **Data-driven assignment of delivery patterns with handling effort considerations in retail**
Presenter: Florian Taube
Discussants: Kristoph Ullrich, Ou Tang

10:00 – 10:45 **Energy storage and inventory management theory**
Presenter: Beatrice Marchi
Discussants: Christos Bitos, Krisztina Demeter

10:45 – 11:15 **Coffee Break**

11:15 – 12:45 **TUTORIAL: Initiating, conducting, and completing research in operations management: Observations from the past twenty years**
Nagesh Gavirneni, Johnson School of Management, Cornell University

12:45 – 14:15 **Lunch Break**

14:15 – 15:00 **Variable neighbourhood search for determining an optimal discount schedule in a two tier supply chain**
Presenter: Viktoryia Buhayenko
Discussants: Florian Taube, Asvin Goel

15:15 – 16:00 **Dual sourcing of critical and conflict materials using recycling options**
Presenter: Patricia Rogetzer
Discussants: Chuanwen Dong, Peter Kelle

16:00 – 16:15 **Coffee Break**

16:15 – 17:00 **An improved bootstrapping method for forecasting spare parts demand using extreme value theory**
Presenter: Sha Zhu
Discussants: Viktoryia Buhayenko, Stefan Minner

17:15 – 18:00 **Optimal replenishment frequency under supply and demand uncertainty**
Presenter: Mervegül Kirci
Discussants: Stephania Mosquera Lopéz, Sandra Transchel

Friday, August 21, 2015

09:00 – 09:45   **The role of agrifood supply chains towards fostering sustainability in the developed world: An integrated system dynamics framework**
Presenter: Naoum Tsolakis,
Discussants: Erica Pastore, Maria Besiou

10:00 – 10:45   **Design of a near-optimal generalized ABC classification for a multi-item inventory control problem**
Presenter: Evan van Wingerden
Discussants: Christian Mandl, Henk Zijm

10:45 – 11:00   **Closing Session**
Sandra Transchel

11:00 – 11:30   **Farewell Coffee**

Tutorials and Keynotes

Global trends of national inventory behavior

Attila Chikán, Professor of Business Economics and Professor of Supply chain Management, also Director of Competitiveness Research Centre
Corvinus University of Budapest (CUB), Hungary

Abstract:
Inventory investment is a very important component of the GDP, its analysis provides fundamentally important information of the national economy. The authors behind this presentation have been doing research to understand and explain the common and also the different features of inventory investment in various countries. We have collected macroeconomic data of the OECD countries (to have a relatively homogeneous group) between 1970 and 2013, and analyzed their connection with annual inventory investment. Our goal is to see the long term characteristics of behavior that is why we concentrated on annual data instead of quarterly series. Using a variety of statistical methods we have analyzed the trends of inventory accumulation over the total time horizon and in various subperiods. We found that the globalization of economic activity has a great impact on national inventory accumulation, leading to rather similar behavior in various countries.
Co-authors: Erzsebet Kovacs and Zsolt Matyusz (Corvinus University of Budapest)
Magdolna Sass (Institute of Economics, Hungarian Academy of Sciences), Peter Vakhal (KOPINT-TARKI)

Short Bio:

Attila Chikán is a Professor of Business Economics and Professor of Supply Chain Management, also Director of Competitiveness Research Centre of Corvinus University of Budapest (CUB). He has been with this university ever since his graduation in 1967. He was Minister Economic Affairs of the Hungarian government in 1998-99 and Rector of CUB in 2000-2003. He has had a number of positions in international organizations, including President, Federation of Europe an Production and Industrial Management Societies (1995) and President, International Federation of Purchasing and Supply Management (1998-2000) and Executive Vice President, International Society for Inventory Research since 1983. He has been on the Boards of several major companies. He is author or co-author of over a dozen of books and two dozens of papers in refereed international journals. He is a member of the Editorial Board of four Hungarian and four international journals. He is a Corresponding Member of the Hungarian Academy of Sciences, a Foreign Member of the Royal Swedish Academy of Engineering, an Honorary Doctor of the University of Babes-Bolyai (Romania) and Lappeenrante University (Finland).

Coordination and collaboration in freight logistics

Henk Zijm, Professor in Production and Supply Chain Management
University of Twente and Dutch Institute of Advanced Logistics, Netherlands

Abstract:
Today's logistics and supply chains are still characterized my major inefficiencies and in addition a very large ecological footprint which render current practices untenable in the long run. For instance, while the European Committee has set targets to reduce Greenhouse Gas Emissions (GGE) in 2015 to 60 % as compared to 1990, we observe that the percentage of transport related GGE has increased from 25 % in 1990 to 36 % currently. Also, average freight truck loads are about 56 %, while more than 20 % of all trucks drive empty, leading to an overall efficiency of only 45 %. At the same time, congestion increases, in particular in densely populated countries or urban areas. As urbanization continues worldwide (already more than 50 % of the world's population is living in urbanized areas, in Western Europe the percentage is already well above 70 %, and still rising), we have to come up with measures to keep cities livable, among which smarter logistics and mobility solutions.

In this talk, I will report on a number of projects at both national and international levels that have been undertaken to address these problems and to propose solutions. In particular, the need for corridor-based multimodal transport networks and smart cross-docking hubs is discussed, as well as the establishment of cross-chain control centers for both horizontal and vertical supply chain coordination, smart solutions for urban logistics and the required digital and physical infrastructures needed to accomplish them. These projects are carried out in the framework of two large innovation clusters, the Effizienzcluster LogistikRuhr, based in NordRhein-Westphalia and the Dinalog cluster in the Netherlands. In addition, we briefly touch on some projects carried out as part of the European Transport Research agenda. An important development is also the official foundation of the European Technology Platform for Logistics ALICE which recently has developed five roadmaps to define a long-term research agenda for logistics and supply chain management. If time permits, I will end with a brief discussion of a long term vision on future logistics and supply chains: the Physical Internet.

Short Bio:
Prof. Dr. W.H.M. (Henk) Zijm (1952) is a full professor in Production and Supply Chain Management at the University of Twente and, until recently, also served as Scientific Director of the Dutch Institute for Advanced Logistics (DINALOG), both in the Netherlands. Prior to his academic career, he worked eight years as senior project manager at Philips Electronics. He has been a consultant to a large number of companies worldwide. Between 2000 and 2009, he served as Dean and subsequently as Rector Magnificus (Vice-Chancellor) of the University of Twente. He has published more than 120 articles in international refereed scientific journals and (co-)authored several books. Professor Zijm is also vice-chair of the European Technology Platform for Logistics ALICE (Alliance for Logistics Innovation and Cooperation in Europe) and is a past president of ISIR (the International Society for Inventory Research, Budapest).

On the usefulness of (laboratory) experiments in OM research and how to actually pull one off

Mirko Kremer, Professor of Supply Chain Management,
Frankfurt School of Finance, Frankfurt, Germany

Abstract:
Laboratory experiments have swiftly become a useful addition to the methodological toolbox of Operations Management researchers. Essentially, controlled laboratory experiments provide substantial control, which makes them useful for those who wish to test the descriptive accuracy of analytical models (as well as those who do not wish to test theory that is not derived from an analytical model). In this tutorial I introduce laboratory experiments and discuss some methodological issues in designing and conducting them.

Short Bio:
Prof. Dr. Mirko Kremer is Professor for Supply Chain Management at the Frankfurt School of Finance & Management. He received his Doctoral degree from the University of Mannheim in 2008, writing his doctoral thesis on "Behavioral perspectives on risk sharing in Supply Chain Management". Before joining Frankfurt School, he was an assistant professor for Supply Chain Management at the Pennsylvania State University (2008-2014), and held visiting positions at INSEAD and the Kellogg School of Management. His research focuses on the impact of managerial and customer (mis)behavior on the performance and design of Operations and Supply Chain systems, with a particular emphasis on micro-behavioral foundations of inventory management, sales forecasting, and queuing/service systems.

Initiating, conducting, and completing research in operations management: Observations from the past twenty years

Srinagesh (Nagesh) Gavirneni, Emerson Professor of Manufacturing Management and Associate Professor of Operations, Technology and Information Management
Johnson School of Management, Cornell University, USA

Abstract:
Disclaimers: This is not a manual for research and I do not believe there can be one. This is personal opinion written down to promote frank and open discussion on these issues. My approach to research is a combination of intellectual activities and practical considerations. I strongly believe that they both go hand in hand. Neither extreme will lead to a fulfilling research career. You will eventually have to find your own path to good research. I hope this will get you started thinking about it.

Initiating Research – Where do ideas come from?
- From the thesis advisor.
- Personal observation of operations or process in practice.
- Articles in popular news outlets and trade journals.
- Interactions with industry folks.
- Attending research workshops and conferences and reading academic journals.

Conducting research
- What are the research questions? Why are they significant?
- What are the expected methodological and managerial contributions?
- Who is the consumer for the research?
- Do you have a complete research team with all the necessary skills?
- Is there a story outline for the paper?

Completing research
- Is research ever complete? – getting published is a good definition of completion.
- Understanding the review process.
- Selecting the appropriate journal for the paper; Choosing the department editor, associate editor, and the preferred reviewers.
- Understanding the referee reports and deciding on the steps going forward; revising the paper according to the referees' requests and writing appropriate responses.
- Patience, perseverance, and persistence are key.

Promoting research
- Presenting it at national and international conferences.
- Sending (by email or regular mail) working papers and pre-prints to colleagues; Using on-line research networks.
- Presenting it at research workshops at other universities.

Finding (and keeping) a job
- Job search is a two-way street. The employer is worried as much as you.
- Be a value-adding member of the community.
- Job search never stops, even when you have a job. Always be looking for the next job. Understand how you like to execute the job search process.

Short Bio:

Professor Gavirneni is the Emerson Professor of Manufacturing Management and Associate Professor of Operations, Technology and Information Management Professor at Johnson School of Management. Professor Gavirneni's research interests are in the areas of supply chain management, inventory control, production scheduling, simulation, and optimization. His papers have appeared in Management Science, Manufacturing & Service Operations Management, European Journal of Operational Research, Operations Research Letters, IIE Transactions, Interfaces, and IEEE Transactions on Reliability. Previously, he was an assistant professor in the Kelley School of Business at Indiana University. Before that he was the chief algorithm design engineer of SmartOps, a Software Architect at Maxager Technology, Inc., and a research scientist with Schlumberger. His undergraduate degree from IIT-Madras is in Mechanical Engineering and he has received Master's degrees from Iowa State University and Carnegie Mellon University.

Book of Abstract

Cash & voucher programs in humanitarian operations

Christos Bitos, Kühne Logistics University, Hamburg, Germany

Cash and voucher programs – giving people money and vouchers instead of or in addition to in kind aid – offer a variety of benefits as a contemporary business model to be employed in underdeveloped communities plagued by natural or man-made disasters. The distribution of cash and vouchers in these communities has developed as a means of replacing the distribution of in-kind aid driven by large international organizations and local NGOs. Giving each individual cash or vouchers, in order to purchase their own goods or services, not only benefits the humanitarian organizations by greatly reducing the transportation costs needed to effectively distribute aid, but also helps to stimulate local economies. With the influx of cash into a local economy and the eventual dissemination of that cash through purchases of fundamentals like food, local economies are more likely to thrive. Thus, cash and voucher programs not only offer immediate aid, but also amplify the effective benefit to a particular community by stimulating the economy for an extended period of time.

Despite its many tangible benefits, cash and voucher distribution programs have faced several challenges in their establishment as norm. As with any financial system, there are multiple stakeholders involved, each with their own and often conflicting goals. The establishment of cash and voucher programs may face issues of effectiveness, as agreements with local suppliers may take up to six weeks to properly organize. Donors also need to allow the transition from in-kind to cash distribution. This transition is often barred by a fear of corruption and inappropriate use of cash and vouchers or ineffectiveness in distribution that decreases donor support for the cause. However, progress is being made to alleviate some of these concerns. Humanitarian organizations hold the responsibility of weighing these factors in combination with a firm understanding of local market capacities and any risk of price inflation in the area. Ultimately, the benefits of the well-established process of providing in-kind assistance into ravaged communities need to be considered against the potential long-term benefits of rebuilding local economies – which implies a need for new capabilities to transit from logistics to local market expertise.

In order to better understand the targeted problem, it is important to start with a thorough literature review of the practitioner research (reports) that have been published on cash and voucher programs by different organizations in recent years (WFP, OXFAM, ECHO etc.). The goal is to acquire a better understanding of the supply chain in the case of cash and vouchers and to find the differences compared to the in-kind aid. This paper aims to identify gaps in the literature regarding the potential use of Cash and Voucher programs and to determine a suitable methodology for dealing with the impacts and trade-offs of this new business model.

Variable neighborhood search for determining an optimal discount schedule in a two tier supply chain

Viktoryia Buhayenko, Sin C. Ho, Aarhus University, Aarhus, Denmark

This research introduces Variable Neighborhood Search for the problem of determining an optimal discount schedule in a two tier supply chain. The supplier decides how much discounts should be introduced and when, to each of the customers, aiming to maximize his profit. The customers, who are heterogeneous in their demand, holding and order costs, get benefits from ordering in periods with discounts, since the resulting price reduction exceeds their increase in inventory and order costs. This research is different from standard yield management where total demand can be affected with prices. Here, the total demand is not influenced with prices, but the periods in which the customer orders are affected.

A low price in one period will induce customers to order in this period; therefore the number of orders in the other periods will decrease. This situation happens in many cases in practice. It is assumed that the supplier has a few big customers. He possesses full information about their demand and costs and can foresee their reaction to a certain discount. As a result, he is able to determine which discount he needs to offer to compensate the increase in the inventory costs of the customers and prompt them into ordering during the desired periods. Thus, the supplier has a possibility to regulate the timing of his own demand using discounts and can benefit from the reduction of his set-up and inventory costs.

Solving this problem to optimality is impossible for large instances due to an exponential number of binary variables. The problem is transformed into a problem of finding the best production periods for the supplier. For this binary decision problem, a swap and a block shift neighborhood are implemented in a Variable Neighborhood Descent. The initial solution is received by solving a problem without discounts. The objective function of each move is calculated by solving a shortest path problem for each customer where a lower bound for the final discounts is used. If this results in an improvement, the exact discounts are calculated and saved as a current best move. Finally, the best move is implemented as the current solution.

The effects on the solution quality and the runtime, while changing neighborhood restrictions are investigated. The introduction of various shaking methods is presented. Shaking is performed as a random new solution generation, random changes to the current solution, as well as including a phase where worsening moves are accepted based on a probability.

An inventory control model for modal split transport: A tailored base-surge approach

Chuanwen Dong, Kuehne Logistics University, Hamburg, Germany
Joint work with Sandra Transchel, Kai Hoberg

Under the pressure of cost saving, companies are searching for simple and applicable approaches to shift volumes from fast transport modes (e.g. truck) to slow transport modes (e.g. trains or barges). Slow modes have longer lead times and lower delivery frequencies due to operational constraints but lower transport costs, while fast modes offer faster shipments and more flexibility at higher costs.

In this context, we develop an inventory control policy to optimize the volume split in the two modes. In a cyclical two-periods inventory model, a constant volume is shipped via the slow mode in the first period of a cycle while flexible volumes can be shipped via the fast mode in both periods of a cycle. The objective of the policy is to minimize the total costs of transport, inventory holding and backorder. Mathematically, our model is a generalized problem of the Tailored Base- Surge (TBS) inventory policy, where we allow different delivery frequencies of both modes.

We find an approximated analytical solution for the constant delivery quantity of the slow mode and the base stock levels in both periods of the fast mode. Our solution gives managers a simple, insightful and easy-to-implement methodology to split volumes between two modes. We find that based on the demand with a coefficient of variance of 0.3, between 33% and 85% of the expected total volume could be split into the slow mode. The modal split ratio depends mainly on the difference between unit transport cost saving and unit inventory holding cost. Numerical results show that our approximation works well.

Integrated field service engineers and spare parts planning maintenance logistics

Sajjad Rahimi Ghahroodi, University of Twente, Enschede, Netherlands

Maintenance logistics is an important discipline that has received considerable attention both in practice and in the scientific literature. This importance is often due to the high investments associated with capital-intensive assets which in turn require a high operational availability. The unplanned downtime of advanced capital equipment can be extremely expensive. Consequently, these unplanned downtimes should be avoided as much as possible and if they occur, it should be kept as short as possible (by using optimal corrective maintenance policies).

The latter implies that malfunctioning parts or components causing the system breakdown are immediately replaced by ready-for-use ones, since repair of the complete system on site requires too much time. This in turn requires an optimal availability of resources (spare parts, tools and service engineers).

So far the planning of resources such as spare parts, service engineers and repair tools has been fragmented and separated. However, any integrated solution encompasses all three types of resources simultaneously. In this research, I focus on the challenging multi-resource planning problem, namely for spare parts and service engineers, for advanced equipment maintenance. In other words, this research is devoted to spare parts inventory control of stocks and planning of Man-power (service engineers) needed to facilitate corrective maintenance.

Suppose we have a network of service regions in which failures happen randomly. There is a service provider that is responsible to solve each of these failures as soon as possible by providing needed spare parts and service engineers. Each service region is agreed upon a certain service level (system availability) with service provider. So, given these system availability constraints, the service provider aims to minimize its total cost by deciding on the amount and location of resources (spare parts and service engineers) through the network.

Optimal replenishment frequently under supply and demand uncertainty

Mervegül Kirci, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

The mitigation of supply-demand mismatches is very important to sustain the profitability of companies that operate in different areas of the world. Companies failing to mitigate supply-demand mismatches suffer from excess inventory charges, particularly due to lost sales and perishable inventory. Companies can reduce supply-demand mismatches by increasing replenishment frequencies. However, there is a trade-off between the benefit of reducing supply-demand mismatches and the cost of transportation or setup costs. This research aims to contribute to the existing literature on multi-period inventory control models by specifying the optimal replenishment frequency under supply and demand uncertainty.

To study the impact of replenishment frequency on mitigating supply-demand mismatches, and find the optimal replenishment frequency in the face of supply and demand uncertainty for perishable products, we consider a food manufacturer who has a yield problem due to spoilage or obsolescence. The manufacturer sells its products to a market with uncertain demand. We model the forecast evolution process using the Martingale model of forecast evolution (MMFE) to capture the impact of the length of replenishment period under fixed setup, overage and underage costs and exposure to uncertainty. We then model the yield problem of the manufacturer by using a queuing model with reneging to optimize capacities. The objective is to reduce material losses thus improving environ- mental performance, taking into account the costs of demand and supply uncertainty.

Our initial findings suggest that for a single item newsvendor model with periodic demand and setup cost, the optimal ordering policy is identical to the newsvendor critical fractile solution. The cost function is thus only dependent on the replenishment frequency. We find the impacts of the setup cost, volatility and product margins on the optimal replenishment frequency. Our results show that the optimal replenishment frequency is monotonically increasing, and the optimality frontier is decreasing over the setup cost. This is intuitive since higher setup costs will cause high total costs if the replenishments are frequent. As the volatility of demand increases, replenishments will increase in frequency to cover the costs of underage and overage. For functional products with low margins, setup costs have a higher impact on the total cost and optimal replenishment frequency. Therefore innovative products are optimally replenished more frequently in comparison to their functional counterparts. Similarly, for high margins, innovative products are replenished more frequently. The optimal replenishment frequency is monotonically decreasing with respect to product margins. Although one would expect a bell shaped curve due to the distribution of demand, the counterintuitive results show a decreasing function in the newsvendor critical fractile. This is explained by the impact of setup costs. When underage cost is low, the setup cost increases the total cost, decreasing the optimal replenishment frequency.

More importantly, our results suggest that by incorporating replenishment frequency as a decision variable, the overestimation of orders for high volatility when using normal distribution for demand can be avoided. In the next step of this research, we will integrate our results with supply uncertainty using a queuing system, and attempt to optimize the production capacities such that the demand and supply uncertainty are jointly minimized.

Implications of additive manufacturing for after sales service logistics

Nils Knofius, University of Twente, Enschede, Netherlands

In this paper, we give an overview of options to improve spare part supply chains with additive manufacturing (AM), identify gaps in the literature, and propose conceptual models to analyze the impact of AM in spare part supply chains. Our models will be contextualized with conditions found in aeronautics, defense and semiconductor industry.

Various institutions attribute AM – also popularly referred to as 3D printing – a bright future. For instance, Canalys (2014) estimates that the 3D printing market, including 3D printers sales, materials and associated services will reach a volume of US$16.2 billion by 2018. This is an increase by more than 400% compared to 2014. Moreover, the assessment of Roland Berger (2014) reveals that investment costs for AM machinery are likely to reduce by 50% within the next 5 years. In general, AM technologies are becoming faster, cheaper, safer, more reliable, and environmentally friendly (Gibson et al., 2010).

The outlined developments are promising if we picture the chances arising from AM in general and service logistics in particular. AM offers various options to improve the design of parts e.g. lighter weight, better heat distribution or reduced amount of sub-assemblies. Moreover, instead of stocking a large variety of slow moving spare parts with high demand uncertainty, these parts may be printed on demand and on location. This not only decreases holding costs and obsolescence risks but also reduces supply chains complexity and (emergency) shipments frequency.

Clearly, these opportunities demonstrate the demand to revisit available theory and investigate how AM may change various trade-offs. Contradictorily, our literature study exposed that the impact of AM on service logistics has received little attention. Given the outlined opportunities of AM, however, it is the responsibility of the academic community to fill this gap and establish guidelines for the business world how and when to adapt AM.

On the basis of several field studies, we envision concrete situations where AM might be a valuable alternative to traditional manufacturing processes (in the future). Opposing to other studies, we elaborate on these findings and propose conceptual models. These may be used to grasp the added value of AM under different circumstances: Among others, we discuss the possible impact of AM on multi-indenture models, repair processes, and dual sourcing layouts. In conclusion, we aim to reveal unanswered questions to the academic community which (will) arise in after sales services due to the advancement of AM technology.

Commodity Spot Market Procurement under Hidden Markov Modulated Prices

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Due to flexibility, but also due to speculation reasons, an increasing number of companies buy their commodities and raw materials like aluminum, copper, oil, electricity or agricultural products at the spot market. This market is characterized by a high volatility in prices. In addition, dynamics in spot market prices are not stationary because of different states of the world (e.g., good or bad economic conditions) a effecting commodities' supply and demand.

Financial research shows that these states (price regimes) are usually not directly and immediately observable, which means that we do not know the current price distribution or price process and its parameters with certainty. Common approaches to deal with non-observable states of the world are hidden Markov regime switching models. Even though these models are well-established in finance, there is, to the best of our knowledge, no work that considers Markov regime switching price processes in a procurement and inventory setting.

Motivated by the idea of partially observed Markov modulated demand (see e.g. Treharne and Sox (2002)), we propose a hidden Markov regime switching approach where price observations at the spot market are considered in order to update probabilistic price regime information derived from historical data in a Bayesian fashion. The objective of this paper is to consider a multi-regime price model as input for a spot market procurement and inventory model.

Our work is related to the basic work of Kalymon (1971), who regards the procurement and inventory problem under stochastic prices for the single-regime case and proofs the optimality of a price-dependent (s,S) policy under the assumption of positive set-up costs for purchases. We show how to interpret the optimal state-dependent inventory policy if the states are not observable. Therefore, we proof that, if the price follows a doubly embedded stochastic price process described by a hidden Markov regime switching model, a base-stock policy is optimal where the base-stock level on the one hand depends on the current price observation (see Kalymon (1971)) and on the other hand on the state (regime) probabilities. Furthermore, we propose an approach for determining the basestock level. In a numerical study, based on historical price data of various traded commodities, the parameters of the hidden Markov model are estimated using the Baum-Welch algorithm. Subsequently, we compare the outcomes of single- and multi-regime price models. Numerical results illustrate the benefits of multi-regime consideration in terms of cost-optimal procurement and inventory decisions.

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Energy storage and inventory management theory

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Renewable and clean energy resources, such as solar, wind, and wave, are experiencing a fast development around the world, thanks to the remarkable benefits introduced on climate, economic and social topics: e.g. lower global warming emissions, improved environmental quality, and stable energy prices. However, these sources are variable, uncertain and not reliable due to their high dependence on the weather. These characteristics cause energy output fluctuations and unpredictability and require additional flexible resources that maintain the balance between energy supply (generation) and demand (load). A way to overcome these issues is, thus, the addition of energy storage systems (EES). In fact, EES can store the energy whenever the production is higher than the demand and supplies electrical energy to the user when needed. Thus, the incorporation of storage devices in renewable systems enables non-simultaneous energy generation and consumption. EES has the potential to stabilize the energy production of renewable energy sources, to increase self-consumption and to allow time shifting (i.e. matching supply and demand of energy).

The device's requirement for time shifting is high-energy capacity (i.e. the device should be able to discharge several MW of power over many hours) and, consequently, high maximum continuous power rating and long full power discharge times. In addition, it is relevant to monitor the inefficiency introduced by the device: thus, it should have relatively low standby losses and high round trip efficiency.

Among the different existing technologies for electrical energy storage, electrochemical storage such as battery is the more suitable in terms of scalability, efficiency, lifetime and discharge time. The management of renewable plants and energy storage system is similar to apply concepts of inventory management and supply chain management to regular commodities. In particular, in the micro- perspective (i.e. the decentralized autonomous energy decisions at a single firm level), the relation between energy production and storage can be managed through inventory theory (newsvendor or warehouse problem): i.e. definition of daily operating policies to manage inventory of stored energy. The present works aims to extend traditional inventory control applying the inventory theory to energy storage modeling: it has been considered the firm's perspective in order to optimize the use of the battery energy storage system that maximizes the firm's own profit. The main contribution of this work is, thus, the analogy between inventory and energy storage model. Moreover, in future work, it should be interesting to observe also different perspectives (macro-perspective, global perspective) for example considering network design decisions and sharing inventories in a supply chain.

A Model of Raw Material Supply under Uncertainty in Commodity Prices, Exchange Rates and Demand: A case study in the Industry of Electrical Cables & Wires

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The most important raw material in the cable & wire industry is the copper wire rod. Colombian cable and wire companies buy copper wire rod from suppliers in China, Chile, Peru, Mexico and Canada. The cost of copper wire rod is the largest component of the variable cost in the electrical cable & wire industry. For this reason, it is very important to analyze the supply model of this kind of raw material to ensure the competitiveness of this industry. In this industry, suppliers have a dominant position and they establish the terms of the contracts. Usually, the Colombian manufacturer must agree to buy a fixed quantity of raw material each month during one year. The common practice is that the provider allocates quotas to different customers requiring to buy copper wire rod.

The main problem of this kind of contracts is that the risk in demand is taken entirely by the buyer, and this constraints their ability to manage their inventory levels. Additionally, the cable and wire manufacturers must face the uncertainty associated with the prices of raw material. The price of wire rod depends on the fluctuations of commodity prices. Most of the time, the price is composed by the price of the commodity plus a premium for manufacturing. We use the prices of copper cathodes in the London Metal Exchange as a reference for the price of the commodity. Another important risk factor in this supply model is the effect of the exchange rate.

However, in the traditional approach of supply models, the optimal inventory levels are determined only by demand, lead time factors and inventory holding costs. These models do not consider the effect of risk factors over the value of the company. Yet, their effect must not be quantified separately, since they are correlated (linearly and non-linearly). Thus, the co-movement of the factors is what must be considered. In this paper we propose a supply model that considers the joint effect of commodity prices and exchange rates based on copulas. The use of copulas enables us to model the multivariate distribution of risk factors, in order to obtain their dependence relationships. The model we propose has the advantage of using high frequency data for the risk factors of interest.

This gives us a better understanding of the volatility in the data series. Hence, we also consider the stylized facts of financial time series in our methodology, by modeling the autoregressive conditional volatility of the risk factors, and by modeling the tails of their marginal distributions by means of extreme value theory. We consider various demand scenarios using an a-priori distribution. To analyze the financial effects on the company value we use robust risk indicators such as value at risk (VaR) and conditional value at risk (CvaR), which are calculated based on the discounted cash flow.

Managing different demand classes in a spare parts inventory: A practical dynamic allocation strategy

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A successful inventory management strategy is focused on reducing as much as possible stock levels and their costs while keeping high service levels in terms of promptness to satisfy customers' demand (Cohen et al., 1990). Optimizing inventory performance means acting across three different dimensions: forecasting, planning and allocation. As in many supply chains a subset of decisions have to be made before customers place the orders, demand has to be predicted with accurate forecast methods. Then, when dealing with planning orders to suppliers, there are other sources of uncertainty, such as suppliers' reliability and their delivery lead time. This is why the second lever for a successful strategy is acting on planning procedures. Finally, often inventory management deals with items for which there are several demand classes. In such a case, it is necessary to allocate stock on hand with different strategies for each class.

In this paper, we focus on the allocation phase with the aim to propose an effective allocation strategy when dealing with two priority demand classes. In fact, as mentioned before, inventory systems often face different types of demand for the same product, according to different priorities. For instance, in an automotive spare parts inventory, the same part can be requested to repair a vehicle out of road (VOR order) or as regular restocking order from the retailer. In such a case, the cost of a VOR backorder is higher than the one associated to regular orders. Hence, different rules should be used to allocate the inventory on hand among orders with different priority, especially when inventory level is down to a few units. In this situation, when an order from the lower class arrives, it might be convenient not to satisfy it and to reserve stock in case high priority orders will arrive.

In the literature, this problem is known as inventory rationing problem (Veinott, 1965). Inventory rationing deals with finding the optimal critical level such that, when inventory on hand falls below that level, low priority orders are no longer filled and parts are reserved for future high priority demand.

Differently from most of the literature on this research area (Möllering et al., 2008; Haynsworth et al., 1989), we pursue the idea of Hung (Hung et al., 2013) of using a dynamic rationing policy: critical levels decrease between two consecutive supplier's deliveries. On one hand, just after the supplier's delivery, the probability of receiving a high priority order is high and so is the total available inventory. Thus, critical levels are higher to cover the long period high priority demand, with negligible effects on the service level on low priority orders. On the other hand, just before the next supplier's delivery, the expected number of high priority orders decreases, and so does the total inventory on hand. Thus, critical levels must decrease to free some inventory for low priority demand. Simulations have been run to

compare the effect of static versus dynamic critical levels on Service Level and inventory investment.

Results show that, fixing the same investment on inventory (i.e., the same ordering pattern to suppliers), the dynamic critical levels lead to higher service levels both for high priority and low priority demand classes than the static allocation strategy.

On the calculation of safety stocks

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Joint work with Aris Syntetos and Ruud Teunter

In the inventory control literature, inventory decisions are generally derived under the assumption that the demand distribution and all its parameters are completely known. In textbooks and software applications this results in either using the one period ahead forecast error as a measure of demand variability, or directly substituting estimated parameters in decision models. The lead time demand variance, essential for safety stock calculations, is then obtained by multiplying the one period ahead forecast error (or the estimated per period demand variance) by the length of the lead time. However, the demand forecast errors are in fact positively correlated and often highly so, even if the underlying demand process exhibits no autocorrelation. This problem exists for all forecasting techniques and demand processes. Whereas inventory decision making under uncertain demand parameters has been studied in single-period models, the correct estimation of order levels and safety stocks when there exists a positive order lead time remains ill-studied.

For systems where demand fluctuates around a constant level and with a constant lead time, we present corrected lead time demand variance expressions. e first derive the exact lead time demand forecast error of mean demand conditional on the true demand variance. That is, we separate the per period forecast errors into the fluctuation of true demand around its true mean, and the fluctuation of the estimator for the mean around the true mean, and subsequently derive the variance of the complete lead time demand forecast error taking into account the correlations between individual terms. We derive safety stock settings based on the corrected expressions, and compare these and the realized service levels to those according to the standard approaches, under the assumption of normally distributed demand.

We subsequently incorporate the additional uncertainty caused by the unknown demand variance. Whereas usually the (biased) sample standard deviation is used to estimate the demand variance, we use an unbiased alternative, and approximate the additional variance term of the lead time demand forecast error that arises from using this estimator instead of the true (unknown) demand variance. This yields a closed-form, corrected safety stock level which preserves linearity in the estimated standard deviation of demand.

Finally, in a numerical study we show that when safety stocks are calculated according to the corrected method, realized service levels are very close to their targets even if the estimates are based on less than 10 observations. Contrarily, the realized service levels according to the standard approaches converge very slowly and significantly undershoot their targets even if the available data set is larger than 50 observations. For realistic parameter choices, traditional approaches can lead to safety stocks that are up to 30% too low and realized service levels that undershoot their targets by up to 10%.

Dual sourcing of critical and conflict materials using recycling options

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Critical and conflict materials are an essential input for the production process of many consumer and industrial products like electronic devices, but also for environmentally-friendly green-energy technology products such as magnets for wind turbines, solar panels and batteries for electric and hybrid vehicles. Critical materials, as for example rare earth elements, are strategic, non-renewable resources that face several supply risks. According to the EU Raw Materials Initiative of the European Commission critical raw materials show high economic importance combined with high risk associated with their supply. Conflict minerals (most prominent ones are tantalum, tungsten, tin, and gold) are natural resources mined in conflict-areas like the Eastern Congo region. They are characterized by systematic exploitation and violations of human rights. Mined conflict materials are passed via illegal trading activities through a non-transparent system of intermediaries to production sites. Supply chain partners have to comply with tedious reporting regulations when sourcing these conflict materials. Therefore the need to recycling of used technical consumer as well as industrial products ('urban mining') to ensure the supply of critical and conflict raw materials is steadily increasing. Whereas the recycling rates of materials like steel, aluminum, and lead are considerably high, the cost-effective recycling of critical and conflict materials is still a challenge. Companies in that respect increasingly face the challenge of securing a steady stream of supply of critical and conflict raw materials for their production.

Due to increasing unreliability of supply and volatility of prices, including recycled raw materials as a second source is highly advisable. Moreover, the processing of recycled materials requires less energy than using new raw materials which can reduce carbon emissions and production cost. To improve the economic, social and environmental sustainability and the resource efficiency of the mentioned products it is necessary to analyze technical as well as supply chain processes of recycling critical and conflict materials.

In this research we investigate a dual sourcing strategy for critical and conflict materials from a primary raw materials supplier and from recycled materials as a secondary source. Hence, we take into account flows of new and returned materials simultaneously. We develop a single period inventory model considering uncertain prices for primary materials, uncertain yield rate from product returns and uncertain demand for finished products as well as their potential dependencies in order to derive optimal order quantities from both sources and optimize the economic and environmental performance. We provide managerial insights in the economic and environmental benefits of dual sourcing with re- cycling and compare this strategy with single sourcing. We conduct a detailed numerical sensitivity analysis on the key input parameters.

The impact of real time yield information on the safety stock in a multistage serial production system

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The production of e.g. semiconductors is heavily influenced by random production yield. In the literature yield losses from 50% up to 80% are mentioned, which cannot be neglected. Another example for random yield is the agricultural sector where yield losses occur due to the not influenceable factor weather.

In this paper we consider an in-house multi-stage serial production system without interim storage between the production stages but with a warehouse for the final product. Each production stage is related to stochastic proportional yield and a production lead time. At the beginning of each period the warehouse can place an order at the production system. Since the optimal ordering policy in case of random yield and positive lead time is very complex, a linear inflation rule is used to determine the production quantity. This means, that the difference between the inventory position and the pseudo order-up-to level is multiplied with the inflation factor to take into account the yield losses. In this study we set the inflation factor equal to the reciprocal of the mean yield of the total production system.

The demand which has to be fulfilled by the warehouse is stochastic and independent and identically distributed across the periods. Demand which cannot be satisfied is backlogged. At the end of each period the average costs of the system, consisting of the average holding and backorder costs, are charged.

In previous literature, Choi, Blocher and Gavirneni (2008) as well as Dettenbach and Thonemann (2015) studied the value of real time yield information for specific make to stock environments. While Choi, Blocher and Gavirneni (2008) use a simulation based approach to analyze a two-stage serial production system, Dettenbach and Thonemann (2015) use dynamic programming to determine the optimal policy. Due to the course of dimensionality, the optimal policy can only be obtained numerically for very small and unrealistic problem sizes. Therefore, they also study a linear inflation policy and use a simulation based approach to determine the pseudo order-up-to level.

In contrast to the papers mentioned above, we use an approximate steady state analysis to obtain an analytical expression for a near optimal pseudo order-up-to level under real time yield information. With this approach we can analyze general systems and are not restricted to one period lead time or one production state with yield. Our analysis enables us to quantify the benefit of real time yield information in a multi stage production system with arbitrary lead times and yield randomness. Further, we derive an easy to implement short formula to determine the safety stock. By means of a numerical study we illustrate the impact of different lead times and yield randomness on the value of real time yield information.

Data-driven assignment of delivery patterns with handling effort considerations in retail

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Focusing on the situation at a big European retailer, we consider inventory control decisions in a supply chain with one warehouse and several stores. The manual processes of order picking at the warehouse and shelf stacking from the store's backroom into the shelves are considered. Demand at the stores is stochastic and non-stationary and might differ from store to store. In that stochastic setting we determine robust delivery patterns and order-up-to levels, which shall remain fixed for a certain time.

Handling costs at the warehouse and stores are included in the model as they are main drivers for logistics costs (see Van Zelst et al. (2009)).

As Curşeu et al. (2008) empirically support an additive structure of different fixed terms and a variable term for explaining the handling effort, we partly base our model on the joint replenishment problem with time-varying deterministic demand (JRPDD). In the JRPDD, major setup costs are incurred for each order, regardless of the number of products. Additional minor setup costs arise for each individual product, making coordinated ordering preferable. We acknowledge that in retail stochastic non- stationary demand structures are apparent. Thus we extend the classic JRPDD by a stochastic yet distribution-free solution approach that optimizes based on multiple historical replications of the target time horizon (e.g. several weeks), an approach introduced by Iyer and Schrage (1992). By doing so, theoretical distributions and their parameters do not have to be fitted to sales data of the company. Instead, this "Big Data" is used as direct input for optimization.

We introduce a mixed integer linear program formulation of the model and to reduce complexity for large scale instances, perform a hierarchical decomposition, where the first-stage problem creates delivery patterns and the second-stage problem assigns those patterns to products and stores and determines appropriate order-up-to levels. For the pattern creation problem we introduce several decomposition approaches and a genetic algorithm.

In a numerical study, we first compare the approaches on randomly created instances based on the data generation scheme by Kirca (1995). When comparing the models against the classic JRPDD on expected demand values, results show that across all instances costs can be cut on average by approx. 2-14 % depending on the approach, with the exact model formulation providing the best solution. In the second part of our numerical study, we apply the decomposition approaches on the large scale case of the European retailer. In that setting, the approaches yield a cost benefit of up to 25 % against the classic JRPDD on expected values.

Hence, the introduced data-driven approach shows that retailers can significantly improve inventory control decisions when incorporating the non-stationary stochastic demand environment in the decision making, while having robust solutions that keep operations stable.

The role of agrifood supply chains towards fostering sustainability in the developed world: An integrated system

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Sustainability and security of food systems emerge as major global concerns that stem from projections that indicate a global population growth to 9.1 billion people by 2050 with a corresponding increase in food demand by 70%. At the same time, it is estimated that nearly 805 million people around the world suffer from chronic hunger, while 2 billion people suffer from hidden hunger. Notably, the malnutrition effect, along with environmental and social challenges rising from food waste, are evident phenomena in the developed countries. To that end, the United Nations Environment Programme indicates the transformation of smallholder farming, by reinforcing the role of short food supply chains, as the way forward within a sustainable development context. In parallel, the European Union funds research to explore the role of smallholdings in global food security and sustainability. Therefore, the need to streamline policy-making regarding small-scale farming within a local agrifood supply chains (AFSCs) framework is pivotal.

In this manuscript, the simulation modelling of sustainability ramifications of AFSCs is performed with refer to social, economic and environmental impacts of local food supply networks in the developed world. To that end, an integrated System Dynamics methodological framework is proposed, as a means to assist decision-makers, local governments and managers towards designing and adopting effective policies for planning, monitoring and assessing the sustainable performance of local AFSCs. The preliminary results indicate that through appropriate governance and effective policy interventions the potentials of enhancing small-scale farming and short AFSCs in the developed world provide promising grounds towards ensuring social cohesion and food security, stakeholders' profitability, and specifically environmental protection through appropriate inventory management and procurement strategies.

This work is a first-effort approach towards the development of a quantitative decision-making support tool that could be employed by policy-makers, including governments, international organizations, and food industry enterprises, for the effective design of value-added strategic interventions for the sustainable development of the agrifood sector.

You Get What You Pay For: CEO Compensation and the Inventory Rhombus

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The appropriate design of incentives has been a major topic in academia and practice in recent decades. As a result of stagnating share prices and the emergence of agency theory during the 1970s, there has been a movement to align executives' compensation with shareholders' interests. Since then, in the United States and nearly all other parts of the world, intense debates have taken place concerning the absolute amount of CEO compensation, its composition, and its effects on managers' decision making. Consequently, over the last 20-30 years, the composition of CEO compensation packages has undergone substantial change. Politicians and the media have recently voiced the criticism that executive compensation excessively rewards short-term decisions and performance; they claim that executives should be held responsible for the long-term consequences of their decisions. Interestingly, although empirical studies analyzed various financial drivers of inventory investments (e.g., gross margins, capital intensity, sales, and SG&A), and the emerging stream of behavioral operations addresses human nature in decision-making processes, we are not aware of any study in the operations management (OM) field that has considered executive compensation as an explanatory variable of inventory investment, even though decisions regarding inventory investments always require a careful tradeoff between the risk of obsolescence and the risk of missing sales opportunities.

As a result of the ongoing changes in the composition of top executive pay, it is time to provide empirical evidence of a relationship between an important organizational feature, the structure of executive compensation, and inventory investments. The characteristics of compensation that we consider are the sensitivity of CEO wealth to the stock price, SSP, and the sensitivity of CEO wealth to stock return volatility, SSV, both of which are frequently at the center of media discussions. Our results highlight that CEO compensation has an impact on inventory investment in multiple direct and indirect ways. In particular, we find that a 20% increase in SSP is associated with a reduction of capital invested in inventory of approximately US$1.652 M. and that moving from the 20th to the 80th percentile in terms of SSP is associated with a reduction of capital invested in inventory of approximately US$22.6 M. This finding confirms that CEOs whose compensation is more dependent on the stock price follow less risky strategies. We further reveal that a 20% increase in CEOs' SSV is associated with an increase of capital invested in inventory of approximately US$0.873 M. This corresponds to an increase of US$ 12.5 M. in capital invested in inventory when shifting from the 20th to the 80th percentile in terms of SSV and reassures that increasing SSV induces risk-seeking behavior. Furthermore, we use the context of this study to show that the triangular interdependent association between inventory investment, gross margin, and COGS, as proposed by past OM research, also applies to manufacturing industries. We complement this model by including sales effort and conceptualize the inventory rhombus.

Design of a near-optimal generalized ABC classification for a multi-item inventory control problem

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Joint work with T. Tan, G.J. van Houtum

In this paper we consider a multi-item, single-location inventory optimization problem. We look at how to design a generalized ABC classification to minimize the inventory investment costs while satisfying an aggregate fill rate constraint. We consider four different aspects of a classification: the classification criteria, the number of classes, the cut-off values, and the target fill rate per class. Using multiple choices per aspect and considering all combinations, we determine the best settings for each aspect. The result of the classifications is measured against the system approach, which specifies a separate fill rate target for each SKU and therefore is difficult to manage. While the system approach is known to give optimal results, we show that near-optimal results can be obtained following our design of a classification by using only four classes and the right settings. We show that a good design of the four aspects is very important for good performance and that the best setting depends on the aggregate fill rate target.

An improved bootstrapping method for forecasting spare parts demand using extreme value theory

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Joint work with Willem van Jaarsveld, Rommert Dekker, Alex Koning

Inventory control for spare parts is essential for many organizations due to the balance between preventing high holding costs and stock outs. The lead time demand is an important parameter in inventory control. The estimation of lead time demand is difficult as the spare part demand is intermittent and limited demand history is available in practice. A simple and practical method is the empirical model, which starts with a window with size lead time from the first period and then moves it one period at a time, constructing the histogram of demands over the lead time. As demands are taken directly over fixed time windows from the data set, this method can capture autocorrelations and fixed demand intervals due to preventive maintenance. It performs reasonably well when service measure targets are relatively low. However, since the empirical method is a non-parametric technique and fails to extrapolate beyond the sample, it has difficulties in obtaining high service measure target, especially in the case of very limited history demands.

In our study, we improve the empirical model by applying the extreme value theory (EVT). As EVT can model the distribution of the sample maximum or the distribution of excesses over the certain threshold, it provides a solid theoretical basis and framework for tail estimation and extrapolation. We use it to estimate the expected waiting time (EWT) and cycle service level (CSL) resulting from extremely large LTD values (values larger than a given upper population quantile). Conditioning on the event that random variable of LTD larger than the given threshold, we can separate the EWT (or CSL) into two parts: the first part is the EWT resulting from the historical data and the second part is that from the potential large values. The first part can be estimated non-parametrically once we have the historic demand data. The second part can be estimated parametrically since we can use EVT to model the LTD distribution of excesses over the given threshold.

We conduct a simulation to assess the performance of our empirical-EVT method, in which the base stock policy with periodic review and full backordering is used. We find that that when limited demand history is available the achieved EWT and the CSL of the empirical- EVT method are more accurate than that of the empirical model for a range of demand distributions and service targets. Under the service measure of EWT, EVT is valid with a certain condition: when the extreme value index of the history data is lower than 1 since the expectation goes into infinity otherwise. We also consider fill rate as the service measure and find that the EVT expression of the fill rate does not change monotonously with the increase of base stock level, which makes the application of EVT under fill rate more difficult. Our findings are particularly useful in the case of expensive spare parts with high shortage cost.

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