OPM 760 – Project Seminar Operations Analytics

Spring Term 2025

The goal of this seminar is conducting of scientific research in the field of operations management. Thereby, it prepares the students for writing an analytics-oriented Master's thesis. The seminar is geared towards students intending to write their thesis at the Chair of Production Management.

Participants will explore one of the topics listed below, designated as either individual or in teams of two students, as specified in the catalog. Team topics can be assigned as individual topics with reduced workload.

Based on scientific literature, participants will apply and implement predictive or descriptive business analytics approaches to solve an operations management problem. They will present their findings in a written report (18 to 22 pages) as well as in an in-class presentation (15 - 20 min + 20 min discussion). Each participant is also expected to critically assess the presentations of the other students in the ensuing discussion.

Applications will be accepted from **November 8th, 2024** until **November 22th, 2024**. Admission to the seminar will be confirmed by e-mail at latest on November 29th, 2024 and must be reconfirmed by the participant at the kick-off meeting.

The **Kick-off meeting** will be held on **December 2nd, 2024** between 12:00 and 13:30 (CET). During this meeting, an introduction to scientific writing and presentations for term papers will be given.

A brief session on introduction to Overleaf and LaTeXwill also be offered. The time and date of this session will be decided in the Kick-off meeting among the interested students.

The **written reports and implementations** have to be submitted by Monday, **March 19th, 2025** in the following formats:

- Two-fold hard copy version.
- Electronic version including a copy of the references cited in the report and auxiliary information (tables, data, programming code, etc.).

The **presentations** will be held as a blocked session during between **1st and 4th April 2025**. Attendance at all presentations is mandatory.

The final grade for the seminar is composed of the following components: Written report (60%), presentation (30%), and contribution to the discussion (10%).

There is a joint application process for all seminars offered by the chairs of the Area Operations Management. In the spring term 2025, this includes the following seminars:

- **OPM 741:** Applied Seminar Supply Chain Management
  Chair of Logistics and Supply Chain Management, Prof. Dr. Moritz Fleischmann
  (Topics labeled with "L"),
- **OPM 760:** Project Seminar Operations Analytics,
  Chair of Production Management, Prof. Dr. Raik Stolletz
  (Topics labeled with "P"),
- **OPM 761:** Research Seminar Production Management,
  Chair of Production Management, Prof. Dr. Raik Stolletz
  (Topics labeled with "P"),

- **OPM 781:** Research Seminar Service Operations Management
  Chair of Service Operations Management, Prof. Dr. Cornelia Schön
  (Topics labeled with "S"),
- **OPM 792:** Applied Seminar Procurement
  Endowed Chair of Procurement, Prof. Dr. Christoph Bode
  (Topics labeled with "B").

Detailed information on the seminar topics and the link to the online registration tool are available on the home pages of the respective chairs. In their applications, students can indicate up to five preferred topics from all seminars.

In addition, applicants for OPM 760 must send an email with (1) CV, (2) official B.Sc. and M.Sc. grades overviews, and (3) the list of courses in the Area Operations that you are currently enrolled in to opm760@uni-mannheim.de. For any further question concerning the seminar please also contact the chair via opm760@uni-mannheim.de.

Topics Catalog

P1 – Capacity planning for renewable energy supply

Type: Individual topic

Objectives:

To fulfill the Paris climate agreement, rapid decarbonization of the global economy in a financially sustainable fashion is imperative. Energy intense manufacturing faces the challenging problem that energy prices increase over time. In addition, to reduce carbon emissions they are interested in producing renewable energy inhouse. This thesis studies the decarbonization of electricity supply by installing a mixture of solar panels and batteries to minimize its time-discounted investment cost, plus the cost of satisfying its remaining demand via conventional grid supply.

The goal of this thesis is to study the strategic decisions on capacities of solar panels and batteries for a long-term planning horizon. An overview of the presented planning procedure and its relation to scientific literature has to be given. The optimization problem and the algebraic model based on a scenario approach has to be described in detail (based on Section 2 of Bertsimas et al. (2023)). The optimization model has to be implemented in Python. Managerial insights on the impact of demand distributions/scenarios on the optimal solution should be derived.

Prerequisites: Knowledge of optimization models and variability (e.g. OPM 661 or 662), prior knowledge in a programming language (e.g. Python)

Basic Paper: Bertsimas et al. (2023)

> **Abstract**: We present our collaboration with the OCP Group, one of the world's largest producers of phosphate and phosphate-based products, in support of a green initiative designed to reduce OCP's carbon emissions significantly. We study the problem of decarbonizing OCP's electricity supply by installing a mixture of solar panels and batteries to minimize its time-discounted investment cost, plus the cost of satisfying its remaining demand via the Moroccan national grid. OCP is currently designing its renewable investment strategy, using insights gleaned from our optimization model, and has pledged to invest 130 billion Moroccan dirham (MAD) (approximately 13 billion U.S. dollars (USD)) in a green initiative by 2027, a subset of which involves decarbonization. We immunize our model against deviations between forecast and realized solar generation output via a combination of robust and distributionally robust optimization. To account for variability in daily solar generation, we propose a data-driven robust optimization approach that prevents excessive conservatism by averaging across uncertainty sets. To protect against variability in seasonal weather patterns induced by climate change, we invoke distributionally robust optimization techniques. Under a 10 billion MAD (approximately 1 billion USD) investment by OCP, the proposed methodology reduces the carbon emissions that arise from OCP's energy needs by more than 70%, while generating a net present value (NPV) of 5 billion MAD over a 20-year planning horizon. Moreover, a 20 billion MAD investment induces a 95% reduction in carbon emissions and generates an NPV of around 2 billion MAD. To fulfill the Paris climate agreement, rapidly decarbonizing the global economy in a financially sustainable fashion is imperative. Accordingly, this work develops a robust optimization methodology that enables OCP to decarbonize at a profit by purchasing solar panels and batteries. Moreover, the methodology could be applied to decarbonize other industrial consumers. Indeed, our approach suggests that decarbonization's profitability depends on solar capacity factors, energy prices, and borrowing costs.

P2 – Optimization for production-inventory planning with intermittent renewable energy

Type: Individual topic

Objectives: With the growing penetration of wind and solar power, both the reliability and the security of renewable energy become a serious concern to utility companies. Thus, wind and solar energy availability should be treated as an uncertain parameter over the planning horizon, and its impact on the production-inventory decision needs to be explicitly considered.

The goal of this thesis is to analyze the production planning problem considering onsite renewable generation, renewable grid, and conventional grid energy. The problem has to be described and modelled as a deterministic MIP (based on Section 3). To account for random renewable energy generation, a scenario approach has to be modelled (simplified version of Section 4). The models have to be implemented in Python and managerial insight based on a sensitivity analysis have to be generated.

Prerequisites: Knowledge of optimization models and variability (e.g. OPM 661 or 662), prior knowledge in a programming language (e.g. Python)

Basic Paper: Golari et al. (2017)

> **Abstract**: A growing number of companies install wind and solar generators in their energy-intensive facilities to attain low-carbon manufacturing operations. However, there is a lack of methodological studies on operating large manufacturing facilities with intermittent power. This study presents a multi-period, production-inventory planning model in a multi-plant manufacturing system powered with onsite and grid renewable energy. Our goal is to determine the production quantity, the stock level, and the renewable energy supply in each period such that the aggregate production cost (including energy) is minimized. We tackle this complex decision problem in three steps. First, we present a deterministic planning model to attain the desired green energy penetration level. Next, the deterministic model is extended to a multistage stochastic optimization model taking into account the uncertainties of renewables. Finally, we develop an efficient modified Benders decomposition algorithm to search for the optimal production schedule using a scenario tree. Numerical experiments are carried out to verify and validate the model integrity, and the potential of realizing high-level renewables penetration in large manufacturing system is discussed and justified.

P3 – Optimization of fleet capacity in urban mobility operations with variable demand

Type: Individual or team topic

Objectives: In many urban mobility services, such as taxi companies, carsharing platforms, and other on-demand transportation services, customers may abandon their ride request (e.g. cancel the ride or switch to another service) due to a lack of patience. For urban mobility services, the number of available vehicles represents a significant investment and cannot be easily adjusted in real-time. Thus, efficient fleet capacity planning (i.e. determining the optimal number of vehicles to invest in and make available) is crucial for success. The fleet capacity planning should consider service level constraints (e.g. 90% of customers experience a wait time of less than 5 minutes), while accounting for time-dependent demand for the rides. Thus, the goal of fleet capacity planning for urban mobility services is to strategically determine the number of vehicles to deploy under time-dependent demand and service level constraints.

However, reliable methods for performance evaluation are needed to optimize the fleet capacity. For example, modified offered load (MOL) and stationary independent period by period (SIPP) approaches can be utilized. MOL approach approximates the time-dependent offered load in a queueing system by the number of busy servers in a corresponding infinite-server system. On the other hand, SIPP approach analyzes the system independently in each period utilizing stationary queueing models.

The goal of this thesis is to analyze the impact of MOL and SIPP approaches on capacity decisions for a time-dependent queueing system with abandonments. Applications and methodology behind MOL and SIPP approaches should be summarized; an overview of capacity planning approaches for time-dependent systems with abandonments should be presented. Capacity planning based on MOL and SIPP approaches should be implemented with Python. The accuracy of these approaches should be analyzed through a systematic comparison against a simulation tool (will be provided by the chair). The differences in obtained capacity decisions based on MOL and SIPP approaches and how these decisions are influenced in face of different system parameters (e.g. service and abandonment rates) should be analyzed in an extensive numerical study.

Prerequisites: Knowledge of stochastic systems (e.g. OPM 661), prior knowledge in a programming language (e.g. Python)

Basic Paper: Liu and Whitt (2012); Green et al. (2001)

> **Abstract**: An algorithm is developed to determine time-dependent staffing levels to stabilize the time-dependent abandonment probabilities and expected delays at positive target values in the $M_t/GI/s_t + GI$ many-server queueing model, which has a nonhomogeneous Poisson arrival process (the M_t), has general service times (the first GI), and allows customer abandonment according to a general patience distribution (the $+GI$). New offered-load and modified-offered-load approximations involving infinite-server models are developed for that purpose. Simulations show that the approximations are effective. A many-server heavy-traffic limit in the efficiency-driven regime shows that (i) the proposed approximations achieve the goal asymptotically as the scale increases, and (ii) it is not possible to simultaneously stabilize the mean queue length in the same asymptotic regime.

P4 – Facility location planning of closed-loop supply chains under stochastic demand

Type: Individual topic

Objectives: In closed-loop supply chains, products used by customers are collected, remanufactured, and subsequently sold to customers again. Optimal planning of closed-loop supply chains necessitate the optimization of locations for production facilities and collection centers, transportation routes, production, recycling, and disposal volumes. Due to the increasing emphasis on sustainability in the manufacturing industry, various environmental goals (e.g., minimizing CO_2 emissions) have to be considered. Additionally, the stochastic nature of customer demand plays a crucial role in planning and must be accounted for.

Optimization of a closed-loop supply chain with stochastic demand can be done with two-stage stochastic programming. The optimization procedure selects the facility location before the uncertain demand is realized (first stage), and adjusts transportation decisions afterwards (second stage). This helps to manage the variability in demand and provides a robust solution. Two key indicators that assess the impact of stochastic demand are the expected value of perfect information (EVPI), and the value of stochastic solution (VSS). While EVPI measures the potential cost savings that could be achieved with a perfect demand forecast, the VSS evaluates benefit of incorporating stochastic variability into the planning process compared to using a deterministic model.

The goal of this thesis is to analyze the impact of stochastic demand distributions on the optimal planning of a facility location problem for a closed-loop supply chain. A literature review should give an overview of objective functions and constraints related to environmental targets used in closed-loop supply chain planning problems. A two-stage stochastic problem for the facility location problem of a closed-loop supply chain should be modelled and implemented in Python. Managerial insights on the impact of demand distributions on the optimal solution, as well as on the EVPI and the VSS should be generated with a numerical study.

Prerequisites: Knowledge of optimization models (e.g. OPM 661 or 662), prior knowledge in a programming language (e.g. Python)

Basic Paper: Amin and Zhang (2013)

> **Abstract**: Integration of forward and reverse channels results in closed-loop supply chain networks. In this research, a mixed-integer linear programming model is proposed to configure a closed-loop supply chain network. The network includes multiple products, plants, recovery technologies, demand markets, and collection centres. The objective function is minimisation of the total cost. The model can determine number and locations of open facilities, and flows of products in the network. In addition, we develop the model to multi-objectives by considering minimisation of defect rates and time of operations in collection centres. To solve the model, weighted-sums and distance methods are applied in copier remanufacturing example and the results are analysed. Moreover, value path approach is applied to compare the results of different methods.

P5 – Waiting for a Better Service: The Quality-Speed Trade-Off

Type: Individual topic

Objectives: In service systems, lower service rates often correspond to services of higher (perceived) quality. E.g., a call center agent might use small talk to calm customers, or spend more time on resolving problems. Another example could be a physician who spends more time diagnosing a patient and thus increasing the quality of treatment. Nevertheless, decreasing the service rate results in higher waiting times. Thereby customer satisfaction suffers. The quality-speed trade-off optimizes service rates to balance waiting and quality. Demand can be determined endogeneously, i.e., the provided service quality and chosen price can influence the demand of future periods.

The objective of this seminar thesis is to describe and analyze the quality-speed trade-off optimization problem with pricing addressed in the base paper in detail. In addition, the paper should be positioned in the related stream of literature. The model presented in the paper should be described, analyzed, and implemented (e.g., in Python, GAMS, etc.). Numerical studies should generate managerial insights. A critical assessment of the model concludes this thesis.

Prerequisites: Knowledge in optimization models and stochastic optimization (e.g., OPM 661 and 662), familiarity with mixed integer programming model implementation on platforms such as Python-docplex, GAMS, AMPL, etc.

Basic Paper: Kostami and Rajagopalan (2014)

> **Abstract**: An important trade-off organizations face in many environments is one between quality and speed. Working faster may result in greater output and less delay, but may result in lower quality and dissatisfied customers. In this work, we consider dynamic models in a monopoly setting to explore the optimal balance among the multiple dimensions of speed, price, and wait time. The impact of quality is captured via the market demand potential, which is a function of the speed (quality) in the previous period. We obtain several results and insights. First, in scenarios where speed may be difficult to change over time (e.g., some automated production lines) but price can be changed, we show that the optimal price charged is such that the demand rate remains constant over time, even though the price and market potential are changing. Furthermore, we identify conditions when the firm will work at a speed that is higher or lower than a benchmark speed and characterize the behavior of prices over time. Second, in scenarios where a firm may not be able to change prices but can adjust the speed each period, the firm starts at a speed that may be faster or slower than a benchmark speed but converges to it over time. In this constant price case, as the benchmark speed increases, the initial speed adopted by the firm is actually lower but increases more quickly thereafter. We also characterize the behavior of price and speed in settings where both can be changed over time. Interestingly, a firm typically starts at a slow speed and increases the speed, price, and demand over time. Although our main model assumes that the firm internalizes the congestion cost, several of our results extend to a scenario where the demand rate is impacted by the congestion level.

P6 – Shift Scheduling: Prescriptive Analytics for Fair Schedules

Type: Individual or team topic

Objectives: Besides creating feasible schedules, fairness considerations are relevant in workforce planning. Employees want to be treated in a fair manner - but as fairness can be a subjective topic, the question is which objective to pursue. In Karsu and Morton (2015), different measures of fairness are presented. Thereby, they differentiate between equitability and balance. The first concept comes into play if customers are indistinguishable, then the goal is to, e.g., allocate some resources over the population or to ensure, that workloads are distributed fairly among employees (Ernst et al., 2004). Balance is important under heterogeneity, e.g., if customers or employees have different preferences regarding products or shift schedules.

This thesis analyzes an optimization model incorporating fairness aspects into the shift scheduling of physicians. Different measures of fairness in the context of workforce planning should be presented, characterized and quantified. The mixed-integer linear programming model (MIP) proposed by Stolletz and Brunner (2012) should be described and briefly positioned within the existing body of literature. Both the reduced set covering and the implicit modeling approach of the model will be implemented using an optimization tool such as Python's DoCPLEX, GAMS, or AMPL. A sensitivity analysis will be conducted, focusing on parameters like minimum and maximum shift length to assess their impact on optimal shift scheduling and provide managerial insights into shift scheduling under fairness considerations.

Prerequisites: Knowledge in optimization models (e.g., OPM 662), prior knowledge in a programming language (e.g. Python)

Basic Paper: Stolletz and Brunner (2012)

> **Abstract**: This research addresses a shift scheduling problem in which physicians are assigned to demand periods. We develop a reduced set covering approach that requires shift templates to be generated for a single day and compare it to an implicit modeling technique where shift-building rules are implemented as constraints. Both techniques allow full flexibility in terms of different shift starting times and lengths as well as break placements. The objective is to minimize the paid out hours under the restrictions given by the labor agreement. Furthermore, we integrate physician preferences and fairness aspects into the scheduling model. Computational results show the efficiency of the reduced set covering formulation in comparison to the implicit modeling approach.

P7 – Flexible Workforce Scheduling under Uncertainty

Type: Individual topic

Objectives: In service systems, the number of customers arriving often depends on the time of day. When creating shift schedules, managers have to consider this time-dependency in order to match supply and demand. In addition, customer demand is in most cases stochastic, i.e., the exact number of customers arriving to the system is not exactly known ex ante. If more workers are assigned than were actually (ex-post) needed, significant costs are incurred from this overstaffing. On the other hand, assigning less workers than actually needed leads to understaffing, and with it the revenues and the quality of service suffers. Some service systems are defined as flexible, e.g., such as in the base paper of Mattia et al. (2017), where two classes of employees exist, where the first class is serving customers and the second class is usually working on customer-unrelated tasks in the back office. However, they can also be used to serve customers by moving them to the front of the office where customer contact takes place. This flexibility is used in case that understaffing occurs, i.e., when the number of scheduled first class employees does not suffice to serve the actual customer demand. Robust optimization can be utilized to solve this shift scheduling problem when incorporating stochastic customer demand. Mattia et al. (2017) minimize the maximum expected costs for reallocating employees from the back office to the front office over all possible realizations of customer demand.

In this thesis, the mixed-integer linear programming model (MIP) proposed by Mattia et al. (2017) should be described and briefly positioned within the existing body of literature. Furthermore, the basic model should be implemented using an optimization tool such as DoCplex, GAMS, or AMPL. A sensitivity analysis has to be designed to show the impact of allocation costs and the variability in the demand pattern on the structure of the optimal shift schedule. A critical assessment of the model and suggestions for future research concludes the thesis.

Prerequisites: Knowledge in optimization models and stochastic optimization (e.g., OPM 661 and 662), familiarity with mixed integer programming model implementation on platforms such as Python-docplex, GAMS, AMPL, etc.

Basic Papers: Mattia et al. (2017)

> **Abstract**: We study the shift scheduling problem in a multi-shift, flexible call center. Differently from previous approaches, the staffing levels ensuring the desired quality of service are considered uncertain, leading to a two-stage robust integer program with right-hand-side uncertainty. We show that, in our setting, modeling the correlation of the demands in consecutive time slots is easier than in other staffing approaches. The complexity issues of a Benders type reformulation are investigated and a branch-and-cut algorithm is devised. The approach can efficiently solve real-world problems from an Italian call center and effectively support managers decisions. In fact, we show that robust shifts have very similar costs to those evaluated by the traditional (deterministic) method while ensuring a higher level of protection against uncertainty.

References

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