OPM 760 – Project Seminar Operations Analytics

Fall Term 2024

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. Workload and scope will be adjusted based on the topic's defined format.

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 **April 26th, 2024** until **May 10th, 2024**. Admission to the seminar will be confirmed by e-mail at latest on May 17th, 2024 and must be reconfirmed by the participant at the kick-off meeting.

The **Kick-off meeting** will be held on **May 21st, 2024** between 8:30 a.m. and 10 a.m. (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, **October 4th, 2024** 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 **10th and 17th October 2024**. 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 fall term 2024, this includes the following seminars:

- **OPM 701:** Research 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 791:** Research 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 – Impact of capacity decisions on service levels in call centers with retrials

Type: Individual topic

Objectives: The interaction between a company and its customers have significant impact for a companies reputation. Therefore, call centers are of high importance as the first point of contact for customers. Customers may leave the queue before being served (e.g. reneging) due to a lack of patience. Some of these customers re-enter the system at a later time point as retrials, others do not return again. Furthermore, call centers decide on the capacity (e.g. number of trunk lines) to find a balance between reducing costs and improving service level. As a result of limited capacity, calling customers might be rejected. This impacts service levels, but also customer satisfaction and companies reputation negatively.

The goal of this thesis is to analyze the impact of service levels on capacity decisions. The resulting differential equations of the corresponding Markov chain should be implemented with Python and solved using a numeric library. Different service levels (e.g. number of rejections, throughput, expected waiting time, ...) should be implemented and analyzed with respect to system capacity. Furthermore, a sensitivity analysis should generate insights on the impact of system capacity and retrials on service levels.

Prerequisites: Knowledge in queueing theory (e.g. OPM 661), prior knowledge in a programming language (e.g. Python)

Basic Paper: Aguir et al. (2008)

> **Abstract**: This paper models a call center as a Markovian queue with multiple servers, where customer impatience, and retrials are modeled explicitly. The model is analyzed as a continuous time Markov chain. The retrial phenomenon is explored numerically using a real example, to demonstrate the magnitude it can take and to understand its sensitivity to various system parameters. The model is then used to assess the impact of disregarding existing retrials in the staffing of a call center. It is shown that ignoring retrials can lead to under-staffing or over-staffing with respect to the optimal, depending on the forecasting assumptions being made.

P2 – Impact of spare-stock policy on the reliability of semiconductor manufacturing lines

Type: Individual topic

Objectives: Semiconductor industry is a very substantial and growing industry, which generated over 600 billion EUR in revenue in 2021. Semiconductors are known as the building blocks of modern electronics, since they form the basis of integrated circuits and are used in virtually all electronic devices (e.g. smartphones, computers, automotive systems, ...). The production of semiconductors necessitates multiple stages, such as wafer slicing, defining the circuit patterns on wafers, annealing, and dicing of integrated circuits. In semiconductor manufacturing lines, the buffer spaces between these stages are limited due to high investment cost. Moreover, machines in production stages can also break down, e.g. due to material fatigue or failure of electronic components, and have to be repaired. A downtime of a production stage can cost up to 72 thousand EUR per hour and are important to manage. While buffers enables different stages to continue production while one other stage has stopped to a failure, it does not increase the availability of a stage. On the contrary, efficiently managing spare parts in production stages can reduce downtimes and increase availability of the system.

The goal of this thesis is to analyze the impact of spare-stock policies and buffer sizes in semiconductor manufacturing lines with unreliable machines. A literature overview on manufacturing lines with unreliable machines should summarize relevant application areas, utilized queueing models, and resulting managerial insights.. The unreliable manufacturing line with limited capacities and spare stock in Sachs et al. (2022) should be modelled as a Markov chain, where the steady-state probabilities and relevant performance measures (e.g. expected throughput, average inventory level, ...) should be calculated with Python. The impact of spare-stock policy, spare part replenishment rates, and buffer sizes between the stations on system performance should be investigated in an extensive numerical study.

Prerequisites: Knowledge in queueing theory (e.g. OPM 661), prior knowledge in a programming language (e.g. Python)

Basic Paper: Sachs et al. (2022)

> **Abstract**: We consider a model of an N-stage flow line with stochastic processing times and interstage buffers that decouple adjacent production stages. Machine downtimes are induced by failures of critical machine components. Each machine is assumed to have exactly one of these failure-prone components. To achieve high machine availability, it is assumed that spare parts for those failure-prone critical components are kept in stock. Failed components are immediately replaced with new, functioning components, and a one-for-one replenishment policy is applied for the restocking of those spare parts. We present a novel decomposition approach to approximate the average throughput and inventory for a system with an arbitrary number of machines, buffers, and spare parts. With a detailed numerical study, we analyze the impact of different parameter constellations on the approximation quality. We demonstrate the remarkable accuracy of our method by comparing our results with both exact and simulated values. Using our method, we further study the complex interaction and partial substitution effects between buffer sizes and spare part base-stock levels on the logistical performance of the flow line.

P3 – Modified offered load approach for staffing service systems with abandonments

Type: Individual topic

Objectives: In many service systems, such as call centers and emergency services, customers leave the queue before being served (e.g. abandonment or balking) due to a lack of patience. In addition to time-dependent arrivals of customers, the total number of available agents and hence the total processing capacity are also time-dependent. To safeguard the performance of such service systems, adequate personnel capacity planning (i.e., determining appropriate staffing levels) is crucial in order to meet a specific service levels at minimal cost. The goal of staffing is selecting the smallest staffing level per period, which results in a satisfactory service level (e.g. 90% of the clients do not wait longer than 5 seconds). However, the resulting staffing pattern highly depends on the performance evaluation approach. Modified offered load (MOL) approach can be utilized to evaluate the performance of a time-dependent system. MOL approach approximates the time-dependent offered load in a queueing system by the number of busy servers in a corresponding infinite-server system.

The goal of this thesis is to analyze the accuracy of staffing with MOL approach for a time-dependent queueing system with abandonments. Applications and methodology behind MOL approach should be summarized; an overview of staffing approaches for time-dependent systems with abandonments and utilized data-sets should be presented. Staffing based on the MOL approach should be implemented with Python. The accuracy of the MOL approach should be analyzed through a systematic comparison against a simulation tool (will be provided by the chair). The impact of system parameters (e.g. service and abandonment rates) on the staffing patterns should be analyzed in an extensive

numerical study.

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

Basic Paper: Liu and Whitt (2012)

> **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 – Impact of performance evaluation on optimal staffing patterns in service systems with abandonments

Type: Team topic

Objectives: In many service systems, such as call centers and emergency services, customers leave the queue before being served (e.g. abandonment or balking) due to a lack of patience. In addition to time-dependent arrivals of customers, the total number of available agents and hence the total processing capacity are also time-dependent. To safeguard the performance of such service systems, adequate personnel capacity planning (i.e., determining appropriate staffing levels) is crucial in order to meet a specific service levels at minimal cost. The goal of staffing is selecting the smallest staffing level per period, which results in a satisfactory service level (e.g. 90% of the clients do not wait longer than 5 seconds). However, the result of staffing depends on the method used for performance evaluation. 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 staffing patterns for a time-dependent queueing system with abandonments. Applications and methodology behind MOL and SIPP approaches should be summarized; an overview of staffing approaches for time-dependent systems with abandonments and utilized data-sets should be presented. Staffing 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 staffing patterns based on MOL and SIPP approaches and how these patterns 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 optimization models and stochastic systems (e.g. OPM 661 or 662), 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 tar-

get 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.

P5 – Staff Planning and Scheduling Under Demand Uncertainty

Type: Individual topic

Objectives: Personnel-related costs are a major component in many service and production systems. Hence, even small percentage reductions in labor costs can lead to significant savings in total costs. Therefore, determining the optimal workforce size and composition is crucial, especially for service systems aiming to balance labor costs against customer service levels. This problem becomes more complicated when demand is stochastic, which is nearly always the case, including in planning for mail processing and distribution centers. Ignoring this stochastic variability can lead to infeasible or suboptimal results. Stochastic optimization models incorporate uncertainty in demand into the mathematical optimization framework, allowing for optimized plans that hedge against various potential demand scenarios.

The goal of this seminar thesis is to provide a detailed description and analysis of the optimization problem addressed in the base paper. This includes identifying the input parameters, decision variables, constraints, and objective function of the optimization problem, as well as the source(s) of stochastic variability. Additionally, the student must place the base paper within the relevant stream of literature. The proposed model should be described and implemented in a modeling system, such as DOcplex in Python. A numerical analysis using a standard solver is needed to produce managerial insights. The thesis will conclude with a critical evaluation of the proposed model's contribution and limitations.

Prerequisites: Knowledge in mathematical modeling and stochastic optimization (e.g. OPM 662)

Basic Papers: Bard et al. (2007)

Abstract: Service organizations that operate outside the normal 8-hour day and face wide fluctuations in demand constantly struggle to optimize the size and composition of their workforce. Recent research has shown that improved personnel scheduling methods that take demand uncertainty into account can lead to significant reductions in labor costs. This paper addresses a staff planning and scheduling problem that arises at United States Postal Service (USPS) mail processing & distribution centers (P&DCs) and develops a two-stage stochastic integer program with recourse for the analysis. In the first stage, before the demand is known, the number of full-time and part-time employees is determined for the permanent workforce. In the second stage, the demand is revealed and workers are assigned to specific shifts during the week. When necessary, overtime and casual labor are used to satisfy demand. This paper consists of two parts: (1) the analysis of the demand distribution in light of historical data, and (2) the development and analysis of the stochastic integer programming model. Using weekly demand for a three-year period, we first investigate the possibility that there exists an end-of-month effect, i.e., the week at the end of month has larger volume than the other weeks. We show that the data fail to indicate that this is the case. In the computational phase of the work, three scenarios are considered: high, medium, and low demand. The stochastic

optimization problem that results is a large-scale integer program that embodies the full set of contractual agreements and labor rules governing the design of the workforce at a P&DC. The usefulness of the model is evaluated by solving a series of instances constructed from data provided by the Dallas facility. The results indicate that significant savings are likely when the recourse problem is used to help structure the workforce.

P6 – Prescriptive Analysis for Efficient Operations of Pumped Storage Hydropower Systems

Type: Individual topic

The use of Pumped Storage Hydropower (PSH) has emerged as a pivotal solution in enhancing the stability and efficiency of renewable energy systems. A significant benefit of PSH lies in its flexibility, allowing it to function as a pump or turbine at different times of the day according to needs. One of the most important aspects of managing such systems is the optimization of the energy storage and release to ensure a harmonious balance between energy demand and supply.

After an introduction to PSH operations optimization models, as well as placement of the base paper in the relevant body of the literature, the thesis analyzes an optimization model to identify the optimal daily operation schedule for PSH systems, focusing on energy storage and release decisions to efficiently balance energy demand and supply. The model proposed by Jia (2013) will be analyzed in detail. The detailed analysis involves describing the mixed-integer linear programming model. The model will be implemented using an optimization tool, such as Python's DOcplex, GAMS, or AMPL. Comprehensive sensitivity analysis will be conducted, focusing on parameters like energy prices to assess their impact on the system's operational strategy. The data ranges required for the analysis must be collected for a region of choice. This numerical analysis seeks to provide managerial insights into the factors affecting PSH efficiency and effectiveness.

Prerequisites: Knowledge in mathematical modeling (e.g. OPM 662), and familiarity with implementing mixed integer programming models (e.g., OPM 560)

Literature: Jia (2013)

> **Abstract**: In this article, a short-term scheduling model for cascaded hydroelectric chain plants with pumped-storage units is discussed, which considers in detail the various factors of the hydro system and units. A mixed-integer linear programming formulation is established. The main contribution of the article is that a systematic method is established such that the complex multivariable production functions of hydro units can be approximated by a piecewise linear function, and the characteristics of pumped-storage units are described by introducing some ancillary integer variables. Numerical testing results show that the mixed-integer linear programming formulation given in this article is efficient and effective.

P7 – 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.

P8 – Shift Scheduling: Prescriptive Analytics for Fair Schedules

Type: Team topic

Objectives: When doing workforce planning, managers are often confronted with different challenges. Besides creating feasible schedules, fairness considerations are relevant. 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.

References

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