Welcome to ORBEL 37

It is with great pleasure that we welcome you in Liège for the 37th edition of the Belgian Operational Research Society's annual conference. This year's edition offers a rich program with two keynote speakers and 77 talks contributed by authors and coauthors from Belgium and from Algeria, Chile, France, Germany, the Netherlands, and the USA. We are grateful to our two distinguished keynote speakers for agreeing to speak at our conference: we are sure that you will enjoy their talks. Thanks to all of you, we will have 25 parallel contributed sessions and in particular two special streams, one dedicated to OR4Logistics and the other one to Data Science. An additional parallel session will be dedicated to presentations by the 2023 ORBEL Award candidates. The ORBEL Award is handed out each year to the best student thesis in operational research and is sponsored by OM Partners. The winner of the award will be announced during the ORBEL Award ceremony on Friday, after which you will be kindly invited to the closing cocktail.

ORBEL 37 is organized by the HEC Liège Centre for Quantitative Methods and Operations Management (QuantOM). More than a formal research institute, QuantOM is an open association of scientists who work under a common label in order to promote and to stimulate the development of research conducted at HEC Liège (or more broadly, within the ULiège) in the field of quantitative methods and of their applications to supply chain management, logistics, operations, and other areas of management and economics. The organization of this conference would not have been possible without the enthusiasm and the dedication of its members, and the help of the administrative staff at HEC Liège. We also thank our sponsors for their financial support: FNRS, Engie, LocalSolver, Gurobi, and OM Partners.

The parallel sessions of this ORBEL edition are hosted in the brand-new building of HEC Liège. HEC Liège is the Management School of the University of Liège (ULiège). The University is an active partner of a network of over 900 universities promoting the exchange of students, researchers, and skills. As a faculty of the University, HEC Liège is one of the leading Belgian management schools hosting graduate and postgraduate study programmes. The School counts 110 full-time faculty members and researchers and about 3,500 students. It promotes an empowering pedagogy leading students to play a proactive part in their education. HEC Liège's commitment to and ongoing investment in quality improvement has been recognized through the international Accreditations AACSB and EQUIS (delivered by EFMD).

We wish you a very interesting and fruitful meeting and a pleasant stay in Liège.

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Plenary session I: Thursday 9:30 - 10:30

Prof. Maria Grazia Speranza
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Optimization in transportation and logistics

Technological changes have been dramatic in the last decades and are changing the way people move and goods are transported. The Internet of Things (IoT) makes objects and places capable of receiving, storing and transmitting information. On the other hand, sustainability is a challenge for institutions, companies, researchers. Coordination opportunities are enormous. A systemic approach to problems and advanced analytical methods are even more vital than in the past.
In this talk, starting from the research carried out in the past, the main trends in the use of optimization models for problems in transportation and logistics will be presented together with some research projects and results. Among the research projects in freight distribution that will be presented: integration of pickup and delivery operations over time, booking of loading/unloading areas in urban distribution, coordination of inbound and outbound transportation operations, optimization of fuel cost in long-haul transportation. Some research projects in people transportation will be also presented: coordination of shared taxi companies, dynamic rebalancing in bike sharing.

Maria Grazia Speranza is a full professor of Operations Research at the University of Brescia, where she served as Dean of the Faculty of Economics and Business and Deputy Rector. She is a former President of IFORS (International Federation of the Operational Research Societies), of EURO (Association of European Operational Research Societies), and of TSL (Transportation Science and Logistics society of INFORMS). As EURO President, she founded the EURO Journal on Transportation and Logistics, the EURO Journal on Computational Optimization, and the EURO Journal on Decision Processes. Her research focuses on mixed integer programming and combinatorial optimization with applications to transportation, supply chain management, scheduling, and portfolio selection. Her recent research is oriented to the study of sustainable mobility problems. M. Grazia Speranza is the author of about 200 articles that appeared in international journals. She has been plenary speaker at several international conferences and member of the scientific committee of the major international conferences in the field. She has been guest editor of special issues of journals, editor of several international journals, and is co-editor-in-chief of the series of books "EURO Advanced Tutorials in Operational Research". She has been a member of many evaluation committees, including the European Research Council (ERC) mathematics panel. She has received the Laurea Honoris Causa from the University of Fribourg (Switzerland).

Plenary session II: Friday 15:00 - 16:00

Prof. Stefan Røpke
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Applications of column generation in machine learning

In the past decade, the popularity of machine learning and AI has grown significantly. As a result, there has been an increased interest in applying machine learning algorithms to improve Operations Research methods. The exchange of ideas also goes in the opposite direction and operations research methods are being employed to improve machine learning algorithms. This talk will focus on the latter subject and we will focus on applications of the column generation algorithm. The talk will begin with a brief introduction to supervised learning, followed by a review of column generation's primary applications within supervised learning. Finally, we will delve into several algorithmic decisions within the LPBoost method, that in practice relies on column generation. LPBoost is closely connected to commonly used machine learning algorithms such as gradient boosting and AdaBoost.

Stefan Røpke is a Professor of Operations Research at the Technical University of Denmark (DTU). He holds a PhD degree in computer science from the University of Copenhagen. He joined the Technical University of Denmark in 2008 after spending two years at a post-doctoral position at CIRRELT at the University of Montreal. Research interests of Stefan Røpke include decomposition algorithms and metaheuristics, especially with applications in transport optimization. Stefan Røpke is the author of the widely used Adaptive Large Neighborhood Search algorithm (ALNS) metaheuristic.

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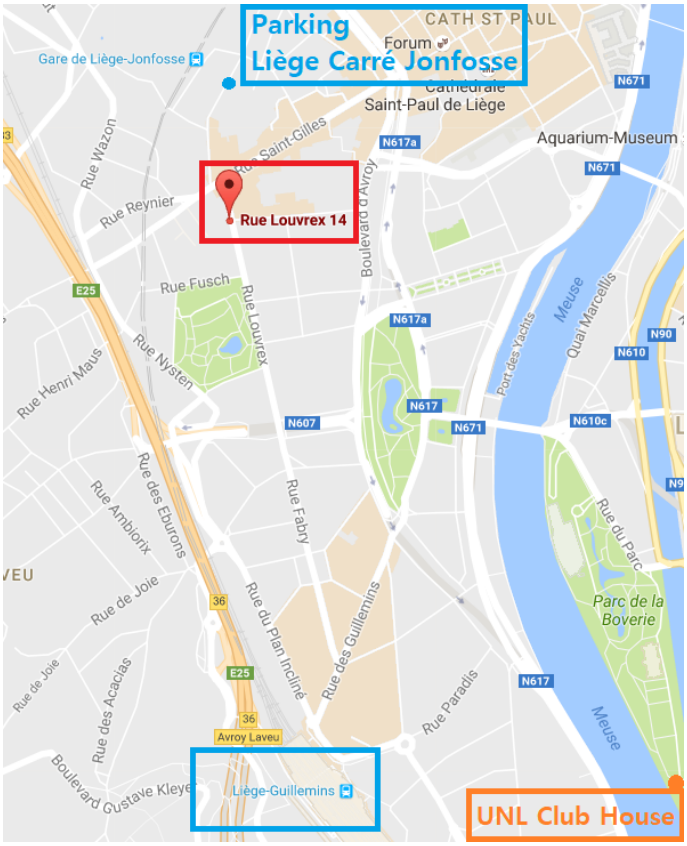
Practical information

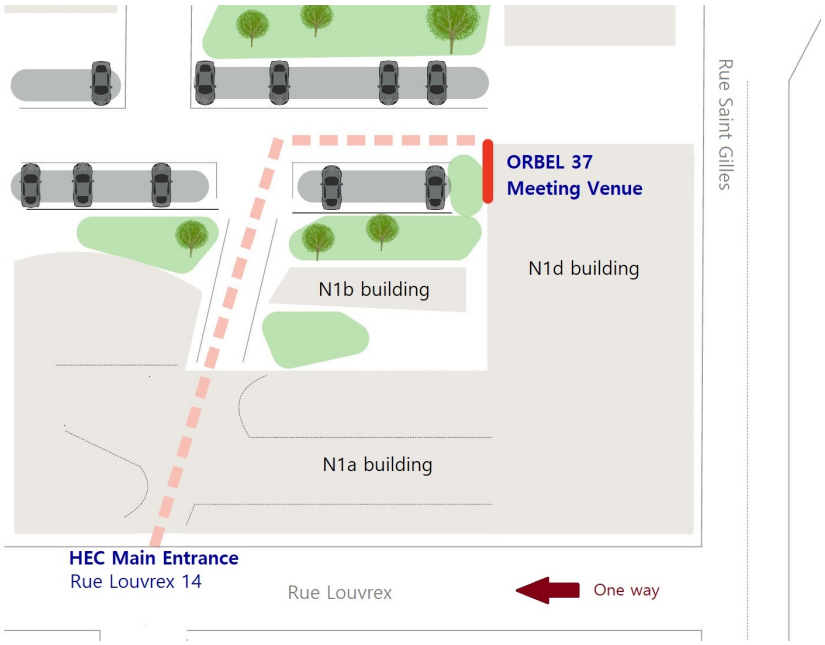
Accessibility

The conference takes place at the N1d and N1a buildings of HEC Liège, Rue Louvrex 14, 4000 Liège. The school is located close to the city centre and just a 15-minute walk away from the Guillemins train station.



The nearest parking is Parking Liège Carré Jonfosse located at Rue Jonfosse 73, 4000 Liège. The fee is 8.90 euros per day.

In order to access the N1d building, enter the N1a building Rue Louvrex 14, then exit the building on the opposite side of the entrance and follow the directions.



Meeting venue

The registration desk will be located at the meeting venue in the **N1d** building, where you will be provided with your name badge and registration pack for the event. Registration will be open from 8:30 AM to 9:15 AM on May 25, 2023.

The plenary sessions on Thursday morning and Friday afternoon take place in Auditorium 030 (N1a building) and the parallel sessions in rooms 0/86, 0/89, 0/88, and -1/86 (ground floor and floor -1 of the N1d building). The conference rooms are equipped with an overhead projector and a video projector using an HDMI port. Please bring your own computer. Each talk is allocated 20 minutes, including discussion. Please note that we are running on a tight schedule. Therefore, it is essential that you limit your presentation to the assigned time. In order to allow inter-session hopping, we ask the chairpersons to follow the planned schedule as faithfully as possible. The two buffet lunches and coffee breaks take place in the school lunchroom in the N1a building. Follow the directions or refer to the map below.

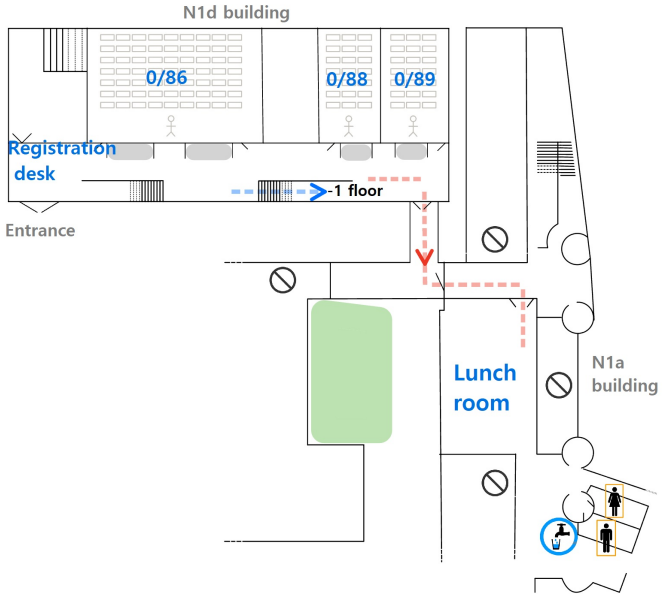


Figure 1: Ground floor of the N1d and N1a buildings of HEC Liège (the dotted line in red is your way from the N1d hallway to the lunch room)

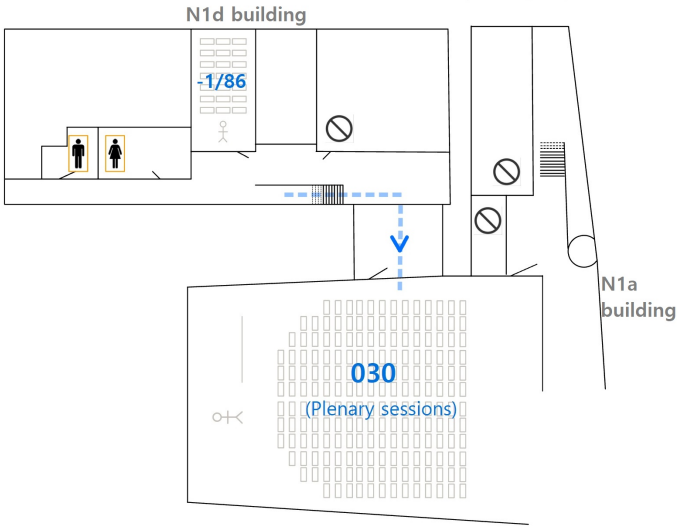


Figure 2: Floor -1 of the N1d and N1a buildings of HEC Liège (the dotted line in blue is your way from the N1d hallway to Auditorium 030)

Conference dinner

The conference dinner is scheduled on Thursday, May 25 at 7PM in the UNL Club House restaurant (Union Nautique de Liège). It is conveniently situated in the heart of Parc de la Boverie, within a 30-minute walking distance from HEC and 15 minutes from the Guillemins train station.

Wifi connection

To connect to the wifi "Guest", you can use the following ID and password:

- ID: **f076599**
- Password: **u8KAiL!H**

General schedule

Thursday, May 25

08:30-09:15	Registration –*N1d* Welcome with coffee and breakfast pastries –*Lunch room*			
09:15-09:30	Opening session			
09:30-10:30	Plenary session I - M.G. Speranza *Auditorium 030* *Chairperson: An Caris*			
10:30-11:00	Coffee break *Lunch room*			
11:00-12:00	Parallel sessions - TA			
	TA 1 OR4Logistics Public transportation *Room -1/86*	TA 2 Data Science Customer analytics *Room 0/86*	TA 3 Local search algorithms *Room 0/89*	TA 4 Cutting and packing *Room 0/88*
12:00-13:30	Lunch *Lunch room* ORBEL board meeting *Room 0/86*			
13:30-14:50	Parallel sessions - TB			
	TB 1 OR4Logistics Location and routing *Room -1/86*	TB 2 Data Science Explainable AI & HR analytics *Room 0/86*	TB 3 Combinatorial problems *Room 0/89*	TB 4 Transportation *Room 0/88*
15:00-15:40	Parallel sessions - TC			
	 OR4Logistics WOG steering committee *Room -1/86*	TC 2 Data Science Segmentation *Room 0/86*	TC 3 Complexity *Room 0/89*	TC 4 Scheduling *Room 0/88*
15:40-16:10	Coffee break *Lunch room*			
16:10-17:10	Parallel sessions - TD			
	TD 1 OR4Logistics Process design *Room -1/86*	TD 2 Data Science Prediction & forecasting *Room 0/86*	TD 3 Energy management *Room 0/89*	TD 4 Covering and location *Room 0/88*
17:15-18:15	ORBEL general assembly *Room 0/86*			
19:00	Gala dinner *UNL Club House*			

Friday, May 26

09:00-09:30	Welcome with coffee *Lunch room*			
09:30-10:30	Parallel sessions - FA			
	FA 1 OR4Logistics Picking and routing *Room -1/86*	FA 2 Data Science Data-driven decision-making *Room 0/86*	FA 3	FA 4 Vehicle routing *Room 0/88*
10:30-11:00	Coffee break *Lunch room*			
11:00-12:00	Parallel sessions - FB			
	FB 1 OR4Logistics Warehousing *Room -1/86*	FB 2 Data Science Text processing *Room 0/86*	FB 3 Individual preferences *Room 0/89*	FB 4 Deep reinforcement learning *Room 0/88*
12:00-13:15	Lunch *Lunch room*			
13:15-14:45	Parallel sessions - FC			
	FC 1 OR4Logistics Integrated planning problem *Room -1/86*	FC 2 Data Science Predictive and prescriptive analytics *Room 0/86*	FC 3 Multi-objective models *Room 0/89*	FC 4 ORBEL Award *Room 0/88*
14:45-15:00	Coffee break *Lunch room*			
15:00-16:00	Plenary session II - S. Røpke *Auditorium 030* *Chairperson: Yves Crama*			
16:00-16:30	ORBEL award and closing session *Auditorium 030*			
16:30-17:30	Farewell drink *Lunch room*			

Detailed program

A demand-responsive public bus system for peak hours with multiple short-cuts and capacitated vehicles

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Keywords: demand-responsive transportation, on-demand transportation, flex-route transportation

In a conventional public bus system, a number of vehicles typically drives back and forth on a fixed-route based on a predefined timetable. The routes and timetables are decided based on historical demand and/or traffic congestion data and made available to the passengers which can make use of the system without bookings in advance.

When demand is high and consistent for a region and time period, these systems perform well due to the high degree of resource sharing. However, because the routes and timetables are re-evaluated mostly in the long-term, they often lose their efficiency and frustrate potential passengers in case of low and/or more variable demand. For this reason, many studies that do not operate with a fixed-route have been proposed in the literature under different names such as *on-demand, demand-responsive, demand-adaptive, flexible, flex-route or variable-type systems* according to the survey of [4].

When the demand for transportation is much higher in one direction than in the opposite direction, buses are often overcrowded in one direction and almost empty in the other in the conventional systems. To improve the efficiency of service in a corridor with uneven demand, [2], [3], and [1] suggest applying stop-skipping and short-cuts. Although the works of [2], [3], and [1] conclude that such strategies are expected to be beneficial both from the passengers' and the operator's point of view under certain circumstances, the optimization of such demand-responsive systems is still lacking.

In this study, we focus on the operation of a single bus line during peak hours where the demand for transportation in one direction is much larger than the demand in the opposite direction. The conventional system operating on this line uses a

number of vehicles driving back and forth between a terminal and a city center following a fixed-route despite the uneven demand. In the system we propose, based on passenger requests, the buses are allowed to take *short-cuts* in order to minimize the total passenger travel time. This means that during peak hours, the system no longer has a fixed headway or a periodic timetable and the service is offered only to those who made an explicit request. Yet, the conventional system operates according to its original fixed-route and timetable without bookings in advance outside peak hours.

When optimizing this system, we consider two scenarios regarding the availability of additional vehicles. If additional vehicles are available in a depot, in that case, they are used to serve the passengers travelling during peak hours in the proposed system. This might be the case when the operator uses smaller vehicles outside peak hours but larger vehicles during peak hours. If additional vehicles are not available or the operator uses the same vehicles throughout the day, then the proposed system takes over from the conventional system before the peak hours and returns back after peak hours. In that case, at the beginning of the operation, the buses that are on the road continue their service according to the original timetable at least until they reach the city center or the terminal for the first time. Then, the departure time and which short-cuts to take is decided for each bus departing from the city center and the terminal based on the passenger requests.

We present Mixed Integer Programs to solve this problem statically. The results show that the demand-responsive system potentially improves the total passenger travel time in case all requests are known in advance. However, to optimize this system in real-time, fast and powerful solution techniques are required.

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A heuristic approach to improve the robustness of a railway timetable in a bottleneck area

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Keywords: Railway transport, Timetable robustness, Railway routing

When a railway network is heavily used, some parts of the network will be nearly saturated. The limited available capacity in these parts is one of the reasons for delay propagation. The propagation of delays is related to the robustness of a timetable. Therefore, our aim is to improve the robustness of a timetable in a bottleneck area. However, the improved timetable cannot deviate too much from the current timetable to ensure the practical applicability for the Belgian railway companies. Therefore, we will start from the current timetable and adjust it by making changes to both the timing and the routing of trains. Additional constraints are imposed to ensure that specific requirements for the railway companies are satisfied.

Robustness is a difficult concept with many definitions and interpretations. Lusby et al. (2018) present an extensive survey on this topic. In Dewilde et al. (2014), the authors strive for a robust timetable by looking for a good spreading in time of the trains by considering the buffer times between them. Our objective function is based on this work. Between each pair of trains that have infrastructure in common, the buffer time is defined as the minimum time span between the two trains. A piecewise linear, monotone decreasing function is used to associate a cost with a buffer time. This function is defined such that the following idea is included: improving a buffer time from 30 seconds to 1 minute is much more valuable than increasing a buffer time of 10 minutes with 30 seconds. Note that the same principle can be obtained by defining the cost as $1/B$. However, we opt for a piecewise linear function because this allows a MILP formulation of the problem. The objective is to minimize the sum of the costs.

Even though a MILP formulation of the problem is possible, solving it within a reasonable amount of time is only possible for small instances. Therefore, a heuristic approach is developed. In a single iteration of the heuristic algorithm, a new, feasible timetable is determined by first updating the routing of the trains, while the timing is fixed, and then adjusting the timing. To find an optimal route selection, a cost graph is defined such that each feasible route selection corresponds to a clique in the

graph. An ILP model is then used to find the clique with the minimal cost. Next, the timing is adjusted by applying a heuristic that looks for the optimal start times for each train separately. When a timetable can no longer be improved by applying these steps, a random, feasible timetable is generated to continue with in the next iteration. The algorithm continues until a maximum computation time is reached.

The developed algorithm is applied to a part of the Belgian network that is centered around the station of Halle. This is located just outside of Brussels, which is the main bottleneck of the Belgian railway network. The results show that the value of our objective function can be improved by about 10% by adjusting the timing and routing of trains. Experiments with smaller instances show that the heuristic is capable of finding near-optimal solutions.

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A multi-agent heuristic for bus line planning

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Keywords: bus line planning, metaheuristics, multi agent system

The Transit Network Design Problem (TNDP), tries to find an optimal set of bus lines, known as a network, to transport passengers [2]. Each bus line consists of a sequence of stops to visit. This sequence is a simple path over a graph. The number of lines and the maximum length of a line is typically given. In this problem, minimising the travel times of the passengers is a common objective function [1]. However, accurately estimating these travel times is not always as obvious, especially when transfers are required. Often, a fixed transfer penalty is considered. By setting this transfer penalty, a certain kind of network is implicitly preferred. For example, if the transfer penalty is high, networks requiring less transfers will be designed. A second concern during line planning is a trade-off consisting of providing improved mobility to most passengers, or requiring that everybody needs to be transported. The first option might provide a network of higher quality, but it will, for instance, only transport 80% of the total passengers. This trade-off is often lost by constraining the solution to networks where all the demand must be met.

Heuristic

In order to address these simplifications, we propose a method that is capable of designing different types of networks at once. The four types of networks considered are: conventional, with a high transfer penalty, with a low transfer penalty, or with a low non-served penalty. In other words, these problems are trained on a different objective function. Each network is given a number of agents specialising in different search strategies. Four main strategies/types of agents are considered: all-round, exploitation, exploration and communication. In other words, every agent can choose between several actions, and depending on the type of agent, certain actions are given a higher/lower probability. The possible actions considered are: replace a current line by a complete new line (exploration), replace a current line by a line from the best solution for this type of network (exploitation), or replace a current line by a line from the best solution from another agent or another network (communication).
New lines in the network can be generated in numerous ways. For this model, it is chosen to take the k-shortest paths from each origin to each destination with demand. These shortest paths are the added to each other, by using the destination of the previous path as origin for the subsequent one. This process is cut off when the maximum line length is reached.

Results

This heuristic is tested on some well-known benchmarks for this specific problem, the Mumford networks [3]. In order to be comparable, all generated networks are, when possible, evaluated with the objective function used in the benchmark. In general, the results are competitive with other presented works, but calculation time seems to be higher. For the Mumford0 network, consisting of 30 nodes, 90 links and 870 non-zero demand origin destination pairs, other works report travel times of 16.05 min, 15.40 min, 14.09 min and 14.88 min [1]. The best solution of this method produced a solution of 14.48 minutes. At the same time, other types of networks were generated which are better suited for another objective function.

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Incorporating usage data for BtoB churn prediction modeling

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Keywords: Usage data, Churn prediction, Machine learning

Customer retention is particularly important in Business-to-Business (B2B) contexts because of high customer acquisition costs and relatively high customer values. Using churn prediction models, firms can implement more effective retention strategies since the outcomes obtained can be applied to customer communication or retention campaigns as a part of their retention strategies.
As mentioned by [1], data is everywhere, and B2B companies are collecting customer data. However the primary focus for companies should be understanding and detecting how to use it. A data source that still remains unexplored in the B2B framework is usage data, which provides insights into how clients use the focal products that allows to derive usage patterns. Based on this information, companies can gain relevant knowledge about their customers. As described by [2], understanding how behavior and patterns of customers evolve provides detailed customer data which could prove useful in decreasing churn rate.
In this paper, we explore the added value of usage data for churn prediction modeling in the B2B context. We use a real-life dataset with 3,959 observations of an

European software provider over a period of 3 years in a contractual setting. With the information available we defined four main categories of features: Firmographics, interactions, behavior and usage.
Our contributions to existing literature are fourfold. First, we compare four most common machine learning classifiers in customer churn prediction (i.e. Decision tree, Logistic regression, Random Forest, and XGBoost) based on their predictive performance measured in AUC, Lift and EMPC. Second, we quantify the global impact of usage variables and demonstrate it as a crucial source of information for churn prediction. Third, we study the improvements obtained from usage variables for churn prediction in terms of time, granularity, and expertise to answer whether when, what or how customer use the product has the greatest impact. Finally, we offer insights regarding the carbon footprint of the entire modeling process required to integrate usage data into different machine learning classifiers.
The initial findings of this research demonstrate the enhanced worth of usage data in improving the predictive accuracy of customer churn prediction models and expected profit of retention campaigns, particularly in the best performing classifier (Logistic regression). Furthermore, this study imparts relevant business insights regarding the integration of usage variables, as examining product usage in multiple time frames provides an overview of customer usage patterns. In this particular context, customers who exhibit a high and effective level of product usage towards the end of their contract are less prone to churn, which highlights the significance of monitoring usage patterns to predict and prevent customer churn.

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Introducing LLM GAMs: Model performance, interpretability, and sparsity in marketing analytics

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Keywords: Prospect Prediction, OR in Marketing, Interpretable AI

In the field of marketing analytics, professionals frequently face the enduring dilemma of finding a balance between performance and interpretability when selecting the most suitable machine learning models for various applications, such as prospect prediction. Prospect prediction aims to model free trial acquisition, allowing users to explore a service at no charge. By analyzing usage statistics and data, these models help predict and target customers who are most likely to convert to paid users. This task, in particular, presents the challenge of balancing performance and interpretability, as understanding the model reveals factors driving customer conversion, which informs marketing strategies and decision-making. Managers are often confronted with the difficult decision of placing their trust in either less accurate models, which may not provide the desired level of predictive performance, or less transparent models, which are harder to understand and interpret. To address this issue, existing research has aimed to improve model performance by combining decision trees and linear logistic models in a hybrid approach, resulting in fully interpretable models with increased performance. In the domain of marketing analytics, a promising approach for enhancing model performance and interpretability involves the combination of decision trees and linear logistic models in a hybrid framework. The Logit Leaf Model (LLM) is one such example, which aims to distinguish customers into segments using a decision tree, and then classify incoming samples through segment-specific logistic regression models [1]. Initially designed for churn prediction, the LLM's general applicability allows it to be adapted for various marketing analytics tasks, including prospect prediction. In later sections, we will explore the application of the LLM to prospect prediction in greater detail, demonstrating its effectiveness in identifying customers most likely to convert to paid users. Considering LLMs' potential in balancing performance and interpretability using lin-

ear models in sub-segments, it is an intriguing task to investigate the integration of LLMs with the flexible Generalized Additive Models (GAMs) in the context of marketing analytics. This work studies the interaction between model performance and model interpretability. In addressing the limitations of existing models like LLM, we identify a gap concerning the unexplored combination of intrinsically interpretable models, decision trees, and Generalized Additive Models (GAMs). Our proposed approach merges these models to enhance performance and interpretability, delving into an area not yet studied or implemented in practice. In general a GAM model can be formally expressed in terms of

$$f(X) = \sum_{i=1}^{m} f_i(x_i) \tag{1}$$

where each f_i describes a shape function that maps the i-th input feature to the output space. Note we can also express a Logistic Regression model using this function by setting $f_i(x) = a_i x_i$, where a_i represents the weight associated with the i-th input feature. Thus, the LLM GAM can be formally defined as the following formula where , $j \in \{1, \ldots, N\}$.

$$f_{\text{LLM GAM}}(X) = \begin{cases} \sum_{i=1}^{m} f_{i1}(x_i), & \text{if } X \text{ belongs to leaf 1} \\ \sum_{i=1}^{m} f_{i2}(x_i), & \text{if } X \text{ belongs to leaf 2} \\ \vdots & \\ \sum_{i=1}^{m} f_{ij}(x_i), & \text{if } X \text{ belongs to leaf } j \end{cases} \tag{2}$$

To evaluate the effectiveness of the LLM GAM in comparison to the original LLM, we employ a prospect dataset, benchmarking both models using 5-Fold Cross Validation and hyperparameter tuning. We assess the predictive quality out-of-sample, in terms of ROC-AUC, Lift, and Top Decile Lift. This evaluation demonstrates the potential of the LLM GAM as an innovative solution for marketing analytics tasks.
In conclusion, this work contributes to the marketing analytics field by introducing the LLM GAM, a model that combines intrinsically interpretable decision trees with the flexibility of Generalized Additive Models. The LLM GAM provides an effective means of balancing performance and interpretability, empowering marketing analysts and managers to make informed decisions based on accurate and transparent machine learning models. Our experimental setup and preliminary results indicate that the LLM GAM holds great promise as a valuable tool for both research and industry settings, and we encourage further exploration and adoption of this approach in the marketing analytics domain.

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The trade-offs of obscuring your digital footprints

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Keywords: Targeted advertising, Privacy, Machine Learning

Introduction A growing part of human life is happening online, including shopping, entertainment, social interactions, and are mediated by digital platforms [4]. This digitalization led to an explosion of online traces we leave behind, think about your Spotify playlist, Google search history of Instagram feed, and creates an extensive picture of our personal habits and preferences [5]. Content that used to be intensely private, and worthy of legal protection, is now freely available to one's network of friends.

People may wish to keep certain aspects of their lives private, such as their sexual or political orientation, and yet this information may be revealed from the digital traces that they leave behind. It has been shown that properties such ethnicity, sexual or political orientation, personality traits, mental health and religious views can be accurately predicted from a set of someone's Facebook likes [4]. Revealing an individual's private traits without their consent or even their knowledge could have very consequential implications: for example, in countries where homosexuality is illegal, governments could obtain the identity of people that are more likely to be homosexual; neo-nazi organizations could identify people in certain regions that are likely to be Jewish; or health assurance companies could attempt to identify people with unhealthy habits (interested in smoking, drugs, fast food, etc.) or specific health problems, and increase their health insurance cost (or even not accept them at all) [2].

But how can we protect the privacy of individuals? Cloaking your digital traces has been suggested as a potential solution in the past. Chen et al (2017) propose a cloaking device that points users to the online traces without which the model would not have made the inference and can thus guide users to better decide which data they feel comfortable sharing. This cloaking device has been shown [3] to be effective; however, it is not clear how effective this mechanism would be over time. There can be a wealth of redundant information in online behavioral data, as it is sparse and extremely high-dimensional, and if the cloaking does not also cover closely related features, one might end up being targeted again in the future [3]. On the other hand, we do not know what the impact will be on other prediction tasks, for which the user still wants to receive personalized content. In this study, we explore the effect of cloaking the metafeatures instead of the fine-grained features and answer the following questions:

- Can cloaking metafeatures instead of fine-grained features avoid future inferences to a further extent?
- What is the impact on desirable inferences when users cloak a larger part of their data?

Materials and Methods We use data from the MyPersonality project, which contains the liked Facebook pages of 58,000 volunteers in the United States, along with their scores on the Big 5 personality traits and some personal characteristics such as gender, age, and sexual / political orientation [4]. We investigate the effect of cloaking gender, political orientation, and sexual orientation. *Cloaking* your data means changing the data of a user so that it was as if the user did not exhibit this behavior (for sparse, behavioral data, this means setting the feature value to zero).

Results We see for all prediction tasks that cloaking metafeatures (MF) is more effective over time than cloaking fine-grained features (FG). This makes sense, as we will hide more features. However, what is the effect of these cloaking strategies on other desired prediction tasks? We assess this by analyzing the difference in performance in predicting the Big 5 traits, before cloaking, after cloaking the fine-grained features, and after cloaking the metafeatures. Surprisingly, we see that both cloaking strategies will have a limited effect on the predictability of the Big 5 traits.

Discussion This research highlights the potential danger of using digital traces to make private inferences about individuals. Many people are unaware of the extent to which online activity can reveal personal information about them, and do not understand how concealing part of their data can have an impact on the performance of other prediction tasks. It should be up to the user to decide whether he is willing to give up some personalization to gain privacy.

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LocalSolver Studio: a platform for optimization prototypes and applications

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Keywords: Software for O.R., Modeler, Solver

LocalSolver Optimizer is a global optimization solver that combines exact and heuristic methods to find near-optimal solutions in minutes. LocalSolver Studio[1] is a web application released in 2023 and built on top of LocalSolver Optimizer. It includes a code editor to write and debug optimization models and a graphical interface to visualize solutions. The optimization is done remotely on dedicated servers with LocalSolver Optimizer. In this talk we will give a demo of LocalSolver Studio and show how it can be used in industry or for teaching.

Context

Operations Research (OR) practitioners have to frequently interact with business experts to build a mathematical model of a real life application. In this context, it is easy to miss business constraints that are obvious for experts. To avoid this problem, one can show business solutions very early in the project, get experts feedbacks and adapt the model. This process requires the combination of several tools: code for data processing, a modeler, a solver and a visualization library. LocalSolver Studio is a tool that combines all these features in one environment for fast prototyping or teaching.

LocalSolver Studio

LocalSolver Studio is in an online code editor combined with a dynamic programming language that includes modeling features. The studio comes with a collection of models for classical operations research problems and a generator for complex variants of routing and scheduling problems. A LocalSolver Studio user can write its own model or modify an example to connect its data and add custom constraints and objectives. The optimization is done remotely on a dedicated server by LocalSolver Optimizer using a combination of exact technics and heuristic approaches. Finally, the solution is transferred back to LocalSolver Studio and can be visualized through graphical widgets in a dashboard. Several widgets are available for route visualization, activity planning, display of indicators, etc.

[1] https://studio.localsolver.com

Once the prototype phase is over, the mathematical model can be directly imported in an application through LocalSolver Optimizer's API. In the near future, the optimization model will be accessible directly through a web service.

Local search profiling in a constraint-based optimization solver

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When solving a combinatorial optimization problem with a heuristic method, such as local search, the quality of the obtained solution is highly dependent on the quality of the procedure itself, since methods in this class generally aim to find a good enough solution in the shortest possible time to be considered effective. In order to evaluate the quality of the search procedure itself, it is necessary to gather data such as profiling information, which may be quite difficult to obtain. In this paper we introduce a profiling mechanism implemented within the OscaR open-source optimization platform [1], particularly for its constraint-based local search framework, OscaR.CBLS.

The generic search procedure structure

A search procedure in OscaR.CBLS is a local search-based heuristic or metaheuristic, meaning that it attempts to solve a problem by exploring its solution space with the aid of *neighborhoods*, which often means that a candidate solution is iteratively improved by applying small transformations called *moves*. In OscaR.CBLS the search procedure is a modular structure composed of two types of neighborhood, meaning either:

- a *NeighborhoodCombinator*: combines several other neighborhoods using a predefined behavior;
- an *EasyNeighborhoodMultiLevel*: an endpoint neighborhood, generating a simple move.

This generic approach grants a high level of customization and control. By changing some parameters of a combinator or by exchanging combinators, the performance and solution quality can be heavily impacted. The impact of these actions can be assessed by profiling some information, such as: the *quality gain* of a neighborhood, the *time spent* in a combinator, the *success* of the combinator, and so forth.

Profiling the search procedure

The profiling process goes through a *profiler* object attached to each neighborhood which gathers data when the neighborhood is called. At the end of the optimization, the resulting profiling data can be displayed on the user's screen.
Thanks to its modular structure, the tree view of the search procedure can be easily generated, which gives a more readable representation. Moreover, the profiler is implemented so that the developer can easily add custom data to profile, such as *event occurrences*.

Conclusion

This contribution to the OscaR.CBLS library can help us define more efficient search procedures, avoiding wasting time with less appropriate combinators for the given problem. It can also allow us to spot bottlenecks and improve slower parts of the code.

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Mixed-variable management by probability features in an evolutionary algorithm

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Keywords: Black-box optimization, Mixed variables, Heuristics

Introduction

Real-life optimization problems generally imply a mixed-variable context where several kinds of variables arise. There are *continuous* variables which are defined over an interval in $\mathbb{R}$. One can also work with *integer* variables, defined over an interval in $\mathbb{Z}$. Two more types of variables can be considered, the *discrete* and the *categorical* ones. *Discrete* variables are only defined for a finite set of elements in $\mathbb{R}$ or $\mathbb{Z}$ (non-exclusive) and *categorical* variables are defined for a set of strings where the elements are unordered (nominal).
One of the main challenges is the handling of the non-continuous variables within the whole optimization process. [2] propose to manage *categorical* variables inside a Particle Swarm Optimization (`PSO`) algorithm. In this work, we consider both continuous and categorical variables and adapt their proposed strategy inside an Evolutionary Algorithm (`EA`). The `EA` we consider here is implemented in `Minamo`, the in-house design space exploration and multi-disciplinary optimization platform developed in the applied research center Cenaero, see [1] for more information.

Developed strategies

In our adaptation of [2], the continuous variables stay untouched, while we associate a probability to each possible "value" of each categorical variable. The initialization of these probabilities is done by defining an equivalent amount for each possible value of each categorical variable, that is, if we consider a categorical variable x_j with n_j possible values defined in $\{v_1, \ldots, v_{n_j}\}$, the associated probabilities will be

initialized to

$$P_{j,k}(0) = \frac{1}{n_j}, \qquad 1 \leq k \leq n_j, \tag{3}$$

where $P_{j,k}$ represents the probability associated to the k-th possible value of the j-th categorical variable. These probabilities evolve during the optimization process and are used in genetic operators such as mutation and crossover to manage the categorical variables. The initialization phase given in Eq. (3) implies that all the possible values of a categorical variable have the same impact in genetic operators at the very beginning of the algorithm.
During the `EA`, the probabilities are updated using the following rule

$$P_{j,k}(t+1) = \alpha P_{j,k}(t) + (1-\alpha)\frac{C_{j,k}(t)}{n(t)}, \tag{4}$$

where t is the current iteration of the algorithm. The quantity $C_{j,k}(t)$ is the number of individuals in the population whose j-th categorical variable at iteration t has the k-th value, while $n(t)$ is the current population size. Rule (4) is directly inspired from [2], where the real value $\alpha \in [0,1]$ is used as a trade-off parameter between the historical value of the probability and the actual state of the search.
During the optimization process, the probabilities are used to handle categorical variables for the genetic operators. The mutation of such variables is done by making a selection of their possible values according to their probabilities. More precisely, a value will have a better chance of being chosen if its associated probability is high. The crossover operator is not referenced in [2] because it is not used in their `PSO` algorithm. We thus propose to use the probabilities to build a two-point crossover operator able to handle categorical variables. More precisely, let us consider two parents with their value and associated probability. If a random value u, uniformly distributed in $[0,1]$, is lower than the maximal probability, then one sets the offspring value to the one corresponding to this probability. Otherwise, the offspring value is set to the one corresponding to the smallest probability.
A first benchmark has been performed to compare the proposed approach with the default `EA` in `Minamo`. This brings encouraging results that motivate us to deepen our strategy in future work.

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A new guided local search heuristic and fast-fail collision-detection system for 2D irregular cutting and packing problems

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Keywords: 2D nesting, irregular shapes, collision detection, guided local search

Cutting and packing problems that feature irregular shapes are widespread and occur in a range of contexts, such as laser cutting, 3D printing and garment cutting.
Determining whether it is possible to place an item at a certain location is an an essential component of the nesting algorithms used to solve such problems. This typically involves ensuring there is no overlap between polygons. Cutting and packing problems with irregular shapes thus not only require us to deal with their combinatorial aspect, but also with the complex geometry of the shapes involved. The efficiency and accuracy of collision-detection methods are therefore crucial in terms of being able to produce quality solutions within reasonable computation time.
Since using exact trigonometry is typically too expensive, common techniques for collision detection in nesting problems include discretization techniques such as rasterization or employing no-fit polygons (NFPs). However, these techniques are not without their limitations. Discretization quickly becomes memory intensive when targeting high precision, while NFP generators often lack robustness. Moreover, a unique NFP must be computed for every possible rotation of every pair of polygons.
In this research we have developed a new collision-detection approach for irregular cutting and packing problems. Our technique is inspired by concepts used in computer graphics and aims to combine speed, accuracy and robustness. It consists of a two-phase approach, where a broad phase aims to efficiently eliminate as much of the required computational work as possible using inexpensive checks. This initial phase involves performing checks on a quadtree-based datastructure. Afterwards, a narrow phase performs edge-intersection and polygon-inclusion tests. These checks are very precise, but also expensive.
Since the collision-detection technique is mainly intended for use in an optimization context, we can safely assume that a collision occurs in the vast majority of queries. We therefore chose to heavily rely on the fail-first principle into our approach, enabling us to resolve over 95% collision-detection queries with almost no computational effort. Given their statistical prevalence, being able to quickly identify and eliminate these 'obvious' collisions greatly improves overall performance, even if this comes at the expense resolving non-colliding more slowly.
On top of this collision-detection technique, we also designed a heuristic to solve the actual optimization problem. While many heuristics in the literature focus heavily on

their constructive strategies, our approach instead focuses on incremental improvement. This is achieved by employing a ruin-and-recreate strategy, which partially destroys and rebuilds the solution each iteration. We combined this strategy with a guided local search that dynamically assigns values to every item. New solutions are accepted if the total value of excluded items is smaller than the previous best solution.
These two components together result in a general 2D nesting algorithm that is capable of handling a range of problem features such as free rotation, irregular-shaped bins, holes and quality zones. Although research remains ongoing, the results produced by our approach are promising. Our results are competitive with the state of the art on traditional nesting benchmarks (simple shapes, very limited rotation) and make significant improvements with respect to Baldacci's leather nesting dataset.

An efficient triangle mesh collision detection approach to three-dimensional irregular open dimension problems

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Keywords: Cutting and packing, 3D Irregular, Continuous rotation

Irregular three-dimensional open dimension problems have not been studied as extensively as either their regular counterparts or their two-dimensional equivalents. This phenomenon appears to hold for other three-dimensional problems with irregular objects. Nevertheless, various approaches to solve the three-dimensional irregular open dimension problem have been proposed in the literature. However, many of these approaches solve variants of the problem where the orientation of the items is fixed and employ techniques that are not capable of easily accommodating continuous free rotation. Examples of such techniques include no-fit polyhedra (NFP), voxelization, semi-discrete representations, and more recently no-fit voxels (NFV). Other techniques can also be difficult to implement robustly for arbitrary shapes. Phi-functions, for example, can only be formulated for elementary shapes and require a decomposition for objects that are more complex.
While fixed rotations can be required due to application-specific demands, such as the printing orientation in additive manufacturing, it is rarely a requirement in other applications. In this research, we leverage collision detection between triangular meshes that represent items to solve these open dimension problems. This results in a general purpose approach that can robustly deal with any irregular shape and can also accommodate the free rotation of items through the use of geometric transformations. To achieve good scaling in terms of object complexity, data structures like bounding volume hierarchies are used to efficiently resolve intersection queries. If needed, approximating the meshes with a lower triangle count can also be considered to tackle more complex, real-world instances.
We initially validate our approach by comparing its performance on multiple data sets against existing results from the literature, while satisfying the exact same rotation constraints. After this, we introduce a modified approach that allows for the free rotation of the items. Although this increases the complexity of the solution search space, we should be able to find high-quality results far more quickly by exploiting these extra degrees of freedom.

Instance space analysis for 2D bin packing mathematical models

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Keywords: Bin Packing, Instance Space Analysis, Mixed integer linear programming

The standard practice of reporting algorithms' average performance across test instances can lead to misleading conclusions if the instances' diversity and suitability are not scrutinized. Additionally, it does not provide insight into each algorithm's strengths and weaknesses. The Instance Space Analysis methodology has recently been developed to provide a robust framework for analyzing algorithm performances. By projecting problem instances onto a two-dimensional space called instance space, this methodology calculates and visually presents the relationships between algorithm performances and features of problem instances. Each algorithm's strengths and weaknesses can be identified, and the suitability of the features calculated and test instances considered can be assessed.
This paper applies the methodology to the 2D Bin Packing Problem, a classic combinatorial optimization problem. For the first time, Instance Space Analysis is applied to mixed-integer programming (MIP) models. MIP formulations of the 2D Bin Packing Problem are treated as our algorithms, and their performance will be assessed by whether the MIP solver CPLEX can solve the models. Ultimately, this analysis will provide insight into the structure of the 2D Bin Packing Problem and factors affecting the solvability of MIP models.

A robust location-routing problem for drone delivery applications

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Keywords: Robust, Drone, Location-routing

Unmanned aerial vehicles, or drones, have found widespread application in diverse fields such as communication, inspection, monitoring and transportation, including delivery services for healthcare, humanitarian and commercial operations. Despite the increasing use of drones in recent years, two critical limitations continue to hinder their further expansion: limited payload and range. While the former restricts the amount of cargo a drone can carry, the latter restricts how far a drone can travel before requiring a recharge. However, recent technological advances in drone technology have helped to mitigate the payload limitation by increasing capacity and enabling drones to deliver multiple items in a single flight. On the other hand, the limited range of drones still poses a challenge due to the lack of charging infrastructure for these devices.

Compared to conventional delivery systems, drone-based delivery systems offer several advantages. For instance, drones can increase the number of deliveries made on time since they are not subject to traffic delays. Furthermore, drone-based delivery systems are more environmentally friendly than delivery systems that rely on trucks, which generate significant carbon emissions. However, one important factor that can directly impact drone deliveries is often neglected in these systems, namely uncertain energy consumption. It is typically assumed that drones travel at a constant speed set by an operator, but they are inevitably exposed to wind, particularly at higher altitudes. In that case, the energy consumption may increase or decrease depending on the wind direction and speed. Therefore, to improve drone-based delivery systems, it is crucial to address the uncertainty in energy consumption due to weather conditions and their impact on drones.

In this work, we propose robust location-routing problems for drone delivery that address the uncertainty in energy consumption in three scenarios: (i) when a drone can only serve one customer, (ii) when a drone can serve multiple customers with a fixed number of total station visits and (iii) when a drone can serve multiple customers with a fixed number of station visits per route. The proposed mathematical models determine optimal charging station locations and routes for each drone while maximizing the total profit obtained from customers served within their respective

time windows and respecting battery capacities. The proposed models ensure the robustness of a solution using dynamic programming equations in the mathematical model, similar to [1]. Additionally, we introduce an adaptive large neighborhood search heuristic [2] (ALNS) for finding solutions in larger instances. We present the results of computational experiments designed to assess the performance of both the mathematical model and ALNS. Furthermore, we demonstrate the advantages of using the robust model compared to its deterministic counterpart through a set of computational experiments.

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Joint parcel locker location and configuration problem considering vehicle routing and alternative delivery mechanisms

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Last-mile delivery of goods from a central depot to customers' homes is becoming more challenging due to rising e-commerce levels and one-day delivery strategies. The use of e-commerce has been rising over the last years; however, the COVID-pandemic catalysed this growth as people avoided brick-and-mortar shopping to reduce their risk of infection. This evolution resulted in increased freight services and more delivery vehicles, corresponding with more urban congestion and emissions [6]. These deliveries are increasingly being made in residential or dense urban areas that are not designed for such large volumes of freight vehicles. To counteract this effect, the use of parcel lockers has been widely proposed as an alternative to home deliveries. The lockers aggregate customer demands, reduce the number of stops made by freight vehicles and decrease the number of failed deliveries, all of which reduces operating costs and potential carbon emissions [6, 1].

When a carrier (e.g., Amazon) wants to use company-owned parcel lockers as a delivery method, three decisions need to be made: (1) the number of locker stations provided, (2) the location of the locker stations and (3) the internal configuration and capacity of the locker stations. Lockers are typically divided into spaces of varying sizes, where smaller parcels would fit into larger spaces, but larger parcels would not fit into smaller spaces. The internal configuration of a locker describes how many spaces of each size are available in one locker station. Different locker configurations are assumed that are available for the carrier to purchase. The three decisions above are interrelated and the success of using parcel lockers instead of home delivery is also dependent on the customer's willingness to use them, their opening cost and the routes delivery vehicles have to drive to get to them. These decisions combined categorize the problem to be solved under the general category of *location-routing*

problems. However, in the case of alternative deliveries with parcel lockers, we also have to decide on where the drop off will take place: in a parcel locker or at home, and in case of a parcel locker, which one would be assigned to which customer?

An optimization problem that combines all these decisions has not yet been investigated in operations research literature. The combination of the internal configuration of parcel lockers and the location-routing with alternative deliveries is particularly identified as a promising research gap [4, 2]. In this talk, we will therefore introduce the joint parcel locker location and configuration problem considering vehicle routing and alternative delivery mechanisms. The problem is of a strategic nature, because the goal of the carrier is to decide on where to place which kind of parcel lockers in the long run, taking into account both its own costs as well as the convenience for its customers. This translates into a weighted objective function that takes both the carrier's perspective (locker opening cost, cost of potential failed home delivery, vehicle usage cost, vehicle distance driven cost) and customer's perspective (inconvenience to travel to a parcel locker) into account. Instead of creating a two-step solution approach to solve the problem, we propose an adaptive large neighborhood search heuristic based on [3, 5] in which both the routing, alternative delivery assignment and parcel locker related decisions are incorporated. Next to introducing the problem and a metaheuristic algorithm to solve it, we will show some preliminary results of our solution approach on artificially generated instances and discuss some future research ideas.

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Progressive filtering for the location–routing problem and variants

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Keywords: Location–routing problem, progressive filtering

Solving the location–routing problem (LRP) involves two essential challenges: determining the depots' locations for executing deliveries and planning the routes of the delivery vehicles from these depots. Over the past few years, many heuristic approaches have been proposed to solve this problem. Most approaches divide the problem into routing and location decision components. Usually, the location component is solved using an approach based on integer programming, whereas the routing component is solved using a constructive or local search heuristic.
This paper proposes an efficient and effective heuristic for the LRP that is based on a different paradigm. The main idea is to start from the set of all possible depot configurations (i.e., solutions for the location decision subproblem), and reduce this set in several steps, until only one solution remains. Additionally, our heuristic is based on an efficient heuristic for the vehicle routing problem.
Our approach first reduces the solution space by estimating an upper bound on the number of open depots. The number of depot configurations is then further reduced in several steps by applying the routing heuristic with an increasing level of precision, filtering out unpromising depot configurations at each step.
This framework, which we call *progressive filtering*, is shown to result in an effective heuristic for the location–routing problem. We demonstrate through extensive experimentation that the estimated upper bound effectively reduces the search space and that a good filtering design combines coarse and fine filters. The final heuristic, despite its simple design, outperforms existing heuristics on the largest LRP benchmark set, on very large-scale LRPs, and 2-echelon LRPs.

Multi-commodity service network design problem with regular and express deliveries

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Keywords: network design problem, vehicle routing, branch-and-price

Problem and research questions

In this research, we study the routing of multiple commodities (shipments) through a network with the aim to minimize the total cost (Salimifard et al., 2022). The problem is motivated by a case study in which a 3PL is responsible for coordinating all material flows that belong to the supply network of a large construction company within Europe (company names are confidential). The network consists of multiple hubs, which either take the form of transshipment points within the supply network or represent a local supply or demand node.
To execute all shipments, the 3PL relies on multiple (often local) carriers. We distinguish between two types of agreements between the 3PL and its subcontractors. First, there is a long-term agreement to establish a periodic fixed capacity on some of the network connections, which we will refer to as the scheduled truck service. For example, a truck is chartered every Monday and Thursday to drive a fixed trajectory. Second, the 3PL can book an ad-hoc express delivery on the spot market.

Methodology, research strategy

We model the network design problem with express deliveries as an mixed integer linear problem (MILP). We hereby focus on a single period with T time intervals (e.g., T can represent one week, which can be subdivided in 7 days, denoted by $t = \{1, \ldots, 7\}$). By imposing that the status of the network (i.e., amount of truck available in each hub) at the end of the period equals the initial status, the logistics plan can easily be repeated for each consecutive period.
To solve this MILP, we apply a branch-and-price (BP) algorithm. Such an algorithm embeds dynamic column generation into a branch-and-bound framework. We apply a best-first branching strategy on the number of trucks one each arc. In each node of the search tree, we apply the column generation algorithm to solve the linear problem relaxation. Each time no additional columns (defined as routes for the scheduled truck service) improve the master problem and the LP-relaxed solution

does not satisfy the integrality conditions we use bounding on each branch and solve two separate column generation for each branch.
We test the presented solution approach extensively on an adapted version of the Canad problem instances (R and C sets) for the multi-commodity network design problem (Hellsten et al., 2021).

Main takeaways

Our study of the relationship between the capacity utilization of the scheduled truck service and the express cost reveals the following: If express costs are too high, and therefore the service is hardly used, we observe that the unused capacity of the scheduled truck service is the highest (on average around 20%). This is explained by the fact that also for the network links for which less consolidation opportunities exist, one prefers to install a scheduled truck service. By making the express service more attractive, inefficient scheduled truck transports are replaced by express delivery up to the point where we see a close to 100% capacity utilization ($\geq 95\%$) of all scheduled trucks in the system.
Another unique feature of our model is the consideration of capacity restrictions in the hubs. As expected, we find that tighter hub capacities lead to higher total network costs. Our simulations show an average cost increase of 10% if only one fifth of the non-binding hub capacity is available. Further analysis reveals that this increase is mainly due to an increase in fleet size for the scheduled truck service and a slightly higher utilization of the express delivery option. The reason is twofold. First, the lack of capacity requires shipments to deviate from their shortest path more often. To accommodate these detours, more capacity is required in the scheduled truck service. Second, these detours increase the cost of a shipment when shipped via the scheduled truck service. Consequently, the express delivery option (which is typically more expensive) becomes more attractive to cover certain connections.
Similar conclusions are found when increasing the inventory holding costs. For increasing values of the holding cost, keeping inventory in the hubs becomes less attractive and more costly. As such, the same decision will be made as when inventory capacity is restricted by the model. We prefer keeping shipments moving on the road by installing a larger fleet of scheduled trucks to bridge the gap between their release time and dispatching time and are willing to accept express deliveries from source to destination more often as no intermediate inventory costs occur then.

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Disagreement amongst counterfactual explanations: How transparency can be deceptive

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Counterfactual explanations are increasingly used as an Explainable Artificial Intelligence (XAI) technique to provide stakeholders of complex machine learning algorithms with explanations for data-driven decisions. The popularity of counterfactual explanations resulted in a boom in the algorithms generating them. However, not every algorithm creates uniform explanations for the same instance. Even though in some contexts multiple possible explanations are beneficial, there are circumstances where diversity amongst counterfactual explanations results in a potential disagreement problem among stakeholders. Ethical issues arise when for example, malicious agents use this diversity to fairwash an unfair machine learning model by hiding sensitive features. As legislators worldwide tend to start including the right to explanations for data-driven, high-stakes decisions in their policies, these ethical issues should be understood and addressed. Our literature review on the disagreement problem in XAI reveals that this problem has never been empirically assessed for counterfactual explanations. Therefore, in this work, we conduct a large-scale empirical analysis, on 40 datasets, using 12 explanation-generating methods, for two black-box models, yielding over 192.0000 explanations. Our study finds alarmingly high disagreement levels between the methods tested. A malicious user is able to both exclude and include desired features when multiple counterfactual explanations are available. This disagreement seems to be driven mainly by the dataset characteristics and the type of counterfactual algorithm. XAI centers on the transparency of algorithmic decision-making, but our analysis advocates for transparency about this self-proclaimed transparency.

Social network analytics for anti-money laundering – A systematic literature review and benchmark

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Keywords: Anti-money Laundering, Network Learning, Benchmark

Money laundering is a global problem, putting a strain on society through unpaid taxes and the financing of illegal activities. Criminals conceal their unlawfully gained money generally in three steps. The first is placement, which consists of introducing the obtained cash into the financial system. The second step, called layering, involves carrying out financial transactions to obscure the link between the assets and their illegal origins. Finally, the third step is integration, whereby the money is spent in apparently legitimate transactions.

Financial institutions are required by law to combat the use of their infrastructure for money laundering. Traditionally, this is done by extensive rule-based checks on clients and their transactions. These rules are costly to maintain, and once known by criminals, can easily be evaded. Therefore, the expert-based rules are being supplemented by machine learning techniques to pick up on more complex fraud behaviour.

Since money laundering involves multiple steps and parties, the incorporation of network analytics in the modelling pipeline is essential. In this research, we look at the current literature on the topic. This work describes the design and results of a systematic literature review on the usage of social network analysis for anti-money laundering, by reporting on the collection of relevant research. Due to the complexity of the problem, most papers only deal with a specific part of the problem.

Using this overview, we present a framework to classify the different studies, and the current gaps in the literature. In addition, we report on the trends identified, allowing us to specify the current state-of-the-art.

Next, we construct a benchmark study based on the methods identified in the literature. The problem of money laundering requires special attention for the choice of models in general. The most prominent obstacle is the absence of labelled data. Since each flagged case needs to be handled by an investigator, there are only limited resources available at in institution to investigate a small fraction of the millions of transactions done. This results typically in less than 1% of cases being labelled as money laundering instances.

For this benchmark, we use different techniques, each having a specific point of view. The main divide is between supervised and unsupervised learning. In addition, there are different ways of capturing network information in the model.

Firstly, one can use classic network features. Some research has been done that uses the degree and centrality measures of a node to featurise the importance of people

and transactions in the network. Summary statistics can be constructed using these features, e.g., the total amount of money moved or the average transaction amount. An important property is the easy interpretability of these features. This facilitates the work of the fraud investigator down the line when they need to determine the legality of the suspicious transactions.
Secondly, more advanced methods try to capture as much network information in a low dimensional embedding. The main obstacle to use networks in machine learning is that they have a non-Euclidean structure. With these methods, we try to translate the network into a Euclidean space, called representation learning, in order to utilise the newly obtained features in a downstream machine learning method. These representation steps generally rely only on the network, and not on the instance specific features.
The third main category consists of deep learning methods applied directly on the network, called graph neural networks. The GNNs have learnable weights, similar to neural networks, and allow to classify the nodes in the network directly by incorporating the non-network features and the information in the neighbourhood of the node. They also allow to construct network representations that can be leverage by other algorithms, but these representations already incorporate instance specific features in some way.
Finally, there is an important branch of research focussing visualising on the transaction network to uncover suspicious patterns. The main problem here is that it scales less well to very large networks.
We see that the second and third type of methods are less widely adopted in the money laundering literature. This relates to the interpretability, or the lack thereof, of the methods and their representations. This results in the main gap in the literature, namely the lack of applications of explainability tools for the deep learning techniques for network representation learning.
In conclusion, this work presents a systematic literature review of the state of network analysis specifically for anti-money laundering. Using these insights, we could construct a benchmark study that compared different methods to each other. Next to the raw results, it compared the interpretability of the methods. We see that there is a trade-off between interpretability and predictive power. Next, the training time and scalability to large networks is highly relevant. Finally, an important issue to do meaningful benchmarking is the lack of freely available data sets.

Hard-to-fill job vacancies: Predicting vacancy durations using explainable machine learning

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Online job vacancy (OJV) platforms have emerged as an important and popular instrument for employers to advertise their job vacancies to a wide pool of candidates [1]. In light of the profusion of available job postings, it is paramount for employers to effectively appeal to and attract suitable candidates, thereby mitigating the costs linked with prolonged job vacancies. Despite the abundant information provided by the widespread adoption of online platforms, prior research has mainly focused on unemployment durations or job-finding rates, while the determinants of the vacancy-filling rate - i.e., vacancy durations - remain a surprisingly largely unexplored field [2]. Of key interest to both employers and providers of OJV platforms, such as public employment services (PES), is to identify ex-ante which vacancies are likely to remain unfilled for longer periods of time. While previous research has demonstrated that non-linear machine learning (ML) algorithms can substantially improve predictions of OJV attractiveness [3], there has been limited research on the application of ML in predicting the duration of OJVs. In collaboration with the Flemish PES, VDAB, the objective of the current paper is to explore the potential of various standard ML algorithms in predicting OJV durations. Specifically, we aim to address the following research questions. First, by analyzing a unique dataset comprising over 400.000 individual OJVs collected by the VDAB, we will investigate the accuracy of different ML models in predicting whether an OJV will be filled within a certain duration. Second, we aspire to identify the key variables that significantly impact the prediction of OJV duration at both the local (i.e. explanations for individual predictions) and global levels (i.e. explanations over multiple predictions), to provide a comprehensive

understanding of the factors that drive OJV durations. For each vacancy the dataset contains information on, but is not limited to, the textual information provided by firms on the VDAB website job postings (e.g., job description, profile, required qualifications and skills, job offer, language), job characteristics (e.g., occupation code, industry, contract type), employer characteristics (e.g,. location, number of job postings), and time-related variables (e.g., timestamps for the (un)publication dates). Finally, we will explore whether counterfactual explanations can be used to gain actionable insights that can be leveraged by employers and providers to minimize vacancy durations. Our work aims to contribute to the existing literature by investigating how textual data inclusion affects the accuracy of ML models in predicting OJV durations and identifying the key factors that drive OJV durations.

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A survey and benchmarking experiment of the state-of-the-art in employee turnover prediction

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Employee turnover presents a significant challenge for organizations. High or unforeseen turnover rates can result in substantial costs to companies, including recruitment, hiring, and training expenses for new employees. Additionally, the loss of valuable employees can lead to a decline in organizational productivity and competitiveness. Predicting employee turnover accurately can help human resource (HR) departments proactively identify employees at risk of leaving and implement retention strategies to maintain workforce stability.

This study provides a clear, structured overview of existing research on employee turnover prediction. Through an extensive literature review, we conclude that existing research results are difficult to compare due to various reasons, such as the use of only a single dataset or classification method. Moreover, experiments conducted across studies do not adhere to a consistent methodology, as evidenced by selective reporting of metrics, inconsistent oversampling, inconsistent tuning of hyperparameters, and an absence of statistical testing to confirm the results.

To address these issues, we conduct an extensive benchmarking experiment with 20 classification methods on 14 datasets, including synthetic and real data. We compare different oversampling techniques to address class imbalance, perform rigorous hyperparameter tuning, report on a wide range of metrics, and statistically test the performance differences of classification methods. Our results show that some methods perform consistently well across datasets, while others depend heavily on specific dataset characteristics.

This study aims to consolidate the existing literature, conduct original experiments,

and extract valuable insights to create a unified and coherent focal point. This resulting focal point will be of great benefit to both industry practitioners and academic researchers seeking to explore the topic in greater depth.

How to design a stable serial knockout competition

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Keywords: Sport Scheduling, Knockouts, Fano plane

Introduction

Two popular tournament formats are the round robin format and the knockout format. In a round robin format, each pair of players (or teams) meet a given number of times. In a knockout tournament, starting from a so-called *seeding*, each round of the knockout tournament sees matches between all remaining players, and a player is removed from the tournament after losing a match; in this way, after $\log n$ rounds a winner is determined (where n is the number of players).
Each of these formats has been studied intensely from very different viewpoints. In particular, deciding upon a seeding of the players in a single knockout tournament has attracted a lot of attention; we do not aim to review this field, and instead refer to the work on which this abstract is based: [1].
In practice, it is not uncommon to design a tournament combining both formats: for instance, first have a number of round robin tournaments in parallel, and then let the winners of the round robins participate in a knockout tournament.
We study a new format that can be seen as an alternative combination of a knockout tournament and a round robin tournament. Let the number of players n be equal to 2^k for some $k \geq 2$, allowing us to focus exclusively on so-called *balanced* knockout tournaments, i.e., knockout tournaments where each player has to play the same number of matches to win the tournament. Observe that a balanced knockout tournament consists of k successive *rounds*, where in round i the remaining 2^{k+1-i} players compete, $i = 1, \ldots, k$.
The competition format we study consists of a set of $2^k - 1$ knockout tournaments. We will call this format a *Serial Knockout Competition*, or SKC for short. The problem that we analyze is to specify, for each of the individual knockout tournaments that make up the SKC, the *seeding*; these seedings specify, for each player, the leaf

nodes of the underlying knockout trees to which the player is assigned, see [1] for an example.
Once the seedings are specified, the individual knockout tournaments of the SKC can unfold - no other decisions in the design of the competition need to be taken. We refer to specifying the seedings as the *design* of the SKC. The question we now focus on is: how to design an SKC in a fair way?
Here, we interpret fair by asking for a design that (i) treats all players equal without any prior assumptions on the strenghts of the players, and (ii) each pair of players should meet equally often in each of the rounds of an SKC.
We will capture the above notions formally by defining the so-called *stability* of an SKC, and the question is: do there exist stable SKC's?
We show, using a connection to the Fano plane, that the answer is yes for 8 players. We show how to generalize this to any number of players that is a power of 2, and we provide stable schedules for competitions on 16 and 32 players.

Motivation: The Premier League of Darts

The motivation for investigating this particular tournament design comes from the Professional Darts Corporation (PDC). We now describe this competition in more detail.
The Premier League of Darts, organized by the PDC, is an annual competition where the best darts players of the world compete over several months for the title. Total prize money is £1.000.000, and the winner pockets £275.000. Basically, the concept of the league is now based on two SKC's. As there is a winner for each of these knockout tournaments, and, importantly, in every single match there is something to play for, the excitement of the format is considered a big improvement compared to earlier formats.
As far as we are aware, this is the first occurence of an SKC in practice. However, we expect that the format of an SKC, or variations thereof, will turn out to be useful and popular in e-sports, as it combines the excitement of a knockout format with the fairness of a round robin format.

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Computing the Frank number of snarks

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An *orientation* o of a graph G is a directed graph with vertices $V(G)$ such that each edge $uv \in E(G)$ is replaced by exactly one of the arcs $u \to v$ or $v \to u$. An orientation is called *strong* if for every two distinct vertices u and v there exists an oriented uv-path, i.e. an oriented path with endpoints u and v. An undirected graph is *k-edge-connected* if it remains connected when fewer than k edges are removed. An orientation of a graph is *k-arc-connected* if it remains strongly connected when fewer than k arcs are removed.

In 1960, Nash-Williams related these two notions by proving that a graph has a k-arc-connected orientation if and only if it is $2k$-edge-connected [3]. However, this does not characterise the cases with odd edge-connectivity. This motivated Hörsch and Szigeti in 2021 to define the following notions for the 3-edge-connected case [2]. An edge e is *deletable* in a strong orientation o of G if the restriction of o to $E(G)-\{e\}$ is a strong orientation of $G-e$. For a 3-edge-connected graph G, the *Frank number* – denoted by $fn(G)$ – is defined to be the minimum number k for which G admits k orientations such that every edge $e \in E(G)$ is deletable in at least one of them.

Hörsch and Szigeti proved in [2] that every 3-edge-connected graph G has $fn(G) \leq 7$ and conjecture that $fn(G) \leq 3$. We study this topic in the case of *cubic graphs*, i.e. where every vertex has exactly three incident edges. This is sufficient since in 2022 Barát and Blázsik [1] showed that for any 3-edge-connected graph G, there exists a 3-edge-connected cubic graph H with $fn(H) \geq fn(G)$.

A graph is 3-*edge-colourable* if one can colour its edges with at most three colours such that no edges incident to the same vertex share a colour. Hörsch and Szigeti [2] were able to show that every 3-edge-connected 3-edge-colourable cubic graph has Frank number at most 3. We strengthen this result by giving a mathematical proof which shows that it is in fact always equal to 2 in this case.

Barát and Blázsik had the idea to look for graphs with Frank number 3 in the class of 3-edge-connected *snarks*, i.e. cubic graphs which are not 3-edge-colourable, motivated by the fact that Hörsch and Szigeti [2] proved that Petersen's graph, a

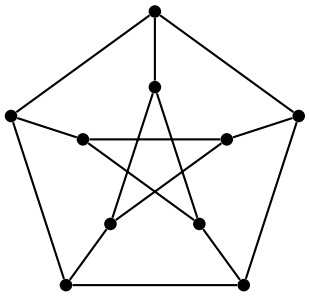

Figure 3: Petersen's graph.

famous snark, have Frank number 3. However, in [1] they were only able to show that the two Blanuša snarks and the infinite family of flower snarks has Frank number 2. Following the idea of Barát and Blászik we determined the Frank number of a large number of snarks. In particular, we performed a computer search on all *cyclically* 4-*edge-connected* snarks, i.e. the minimum number of edges whose removal separates two cycles in the graph is 4, up to and including order 36 and determined that apart from Petersen's graph all these snarks have Frank number 2.
Our approach combines a heuristic and an exact algorithm for determining whether or not a graph has Frank number 2. For the exact algorithm, we look at the strongly connected orientations of the graph and try to create an orientation which is complementary to the one currently under consideration. Using properties that should be satisfied for two such orientations, we try to prune the search as quickly as possible. Due to the great number of graphs we wanted to check (approximately 400 million) only using this approach was computationally infeasible. Therefore, we also made use of a heuristic algorithm. This determines the presence of either of two configurations in a cyclically 4-edge-connected snark, which provides a sufficient condition for the graph to have Frank number 2. If neither of these configurations was present, which occurred in less than 1% of cases, we applied the exact algorithm. In total these computations took approximately 214 CPU-days.
Our results give good evidence in support of the conjecture of Hörsch and Szigeti and the fact that Petersen's graph may be the only cyclically 4-edge-connected cubic graph with Frank number greater than 2.

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Facets of the connected partition polytope

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Keywords: Connectivity, polyhedral study, separation

Many combinatorial problems consist in finding partitions of the set of vertices of a graph into classes that induce connected subgraphs. This idea of dividing into connected parts (classes) plays an essential role in many applications arising in image processing, cluster analysis, political districting, and bioinformatics [4, 5, 1, 6].
Let k be a positive integer, $[k] = \{1, \ldots, k\}$ and let G be a (undirected) graph with n vertices. We denote by $V(G)$ and $E(G)$ the sets of vertices and edges of G, respectively. A *connected k-subpartition* $\mathcal{V} = \{V_1, \ldots, V_k\}$ of G is a collection of k pairwise disjoint sets of vertices in $V(G)$ such that each set induces a connected subgraph, that is, $V_i \cap V_j = \emptyset$ for all $i, j \in [k]$ with $i \neq j$, and $G[V_i]$, the subgraph induced by V_i, is connected for every $i \in [k]$. A collection $\mathcal{V}$ is a *connected k-partition* if additionally $\bigcup_{i\in[k]} V_i = V(G)$.
Given a set of vertices $V' \subseteq V(G)$ and $c \in [k]$, we define the vector $e(V', c) \in \{0, 1\}^{kn}$ such that its non-null entries are precisely $e(V', c)_{v,c} = 1$ for all $v \in V'$. Let $\mathcal{V} = \{V_1, \ldots, V_k\}$ be a k-subpartition of G. The non-null entries of its *incidence vector* $\chi(\mathcal{V})$ are precisely $\chi(\mathcal{V})_{v,c} = 1$ for every $c \in [k]$, $v \in V_c$, that is, $\chi(\mathcal{V}) = \sum_{c\in[k]} e(V_c, c)$. The connected k-partition polytope of G, denoted by $\mathcal{P}(G, k)$, is defined as $\mathcal{P}(G, k) = \text{conv}\{\chi(\mathcal{V}) \in \{0, 1\}^{nk} : \mathcal{V}$ is a connected k-subpartition of $G\}$.
Given any pair of non-adjacent vertices $uv \notin E(G)$, a *u, v-separator* is a set of vertices $Z \subseteq V(G) \setminus \{u, v\}$ such that u and v belong to different components of $G - Z$. Let us denote by $\Gamma(u, v)$ the set of all minimal u, v-separators in G. Consider now the following inequalities in $\mathbb{R}^{nk}$.

$$\sum_{c\in[k]} x_{v,c} \leq 1 \qquad \forall v \in V, \tag{5}$$

$$x_{u,c} + x_{v,c} - \sum_{z\in Z} x_{z,c} \leq 1 \qquad \forall uv \notin E(G), Z \in \Gamma(u, v), c \in [k], \tag{6}$$

$$x_{v,c} \geq 0 \qquad \forall v \in V \text{ and } c \in [k]. \tag{7}$$

Let us denote by $\mathcal{P}'(G, k)$ the set of all vectors $x \in \mathbb{R}^{nk}$ satisfying (5)-(7). Observe that if two non-adjacent vertices u and v belong to a same class c, then there must exist a path between u and v such that every internal vertex also belongs to class c, and such a path intersects every u, v-separator in G. It follows from this remark that $\mathcal{P}(G, k) = \text{conv}(\mathcal{P}'(G, k) \cap \{0, 1\}^{nk})$.
The facial structure of the polytope $\mathcal{P}(G, k)$ was studied before by Campêlo et al. [2] in the context of a polyhedral approach to the Convex Recoloring problem. This problem consists in finding a (re)coloring of a given colored graph such that each color

class in the recoloring induces a connected subgraph, and the amount of recolored vertices is minimized. Moran and Snir [6] proved that Convex Recoloring is NP-hard even on paths.
Wang et al. [7] presented a detailed polyhedral study for the case $k = 1$. More precisely, they showed that (6) induces a facet of $\mathcal{P}(G, 1)$ if, and only if, Z is minimal. They also proved that the *indegree* inequalities, known to induce all nontrivial facets of $\mathcal{P}(G, 1)$ when G is a tree (see Korte et al. [3]), are valid for general graphs and can be separated in linear time. The indegree inequalities can be generalized to the case of positive k in a trivial way as follows. Consider an orientation $\vec{E}$ of the edges in G, and define, for each $v \in V(G)$, $d(v)$ as the number of arcs in $\vec{E}$ with head v. The indegree inequality corresponding to $\vec{E}$ and $c \in [k]$ is $\sum_{v \in V}(1 - d(v))x_{v,c} \leq 1$.
This work is devoted to study of the facial structure of $\mathcal{P}(G, k)$ and the computational complexity of the corresponding separation problems. First we introduce a class of inequalities for $\mathcal{P}(G, k)$ that generalizes both connectivity inequalities (6) and indegree inequalities. The proposed class unifies these two classes from the literature, and contains new strong valid inequalities. We show that the separation problem associated with these inequalities can be solved in polynomial time (when an arbitrary partition of the vertices is given) by reducing it to a quadratic number of bipartite instances of the Minimum Weighted Vertex Cover problem. We also introduce valid inequalities for $\mathcal{P}(G, k)$ that combine multiple classes, and show when they are facet-defining. Moreover, we investigate the computational complexity of solving the corresponding separation problems.

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A routing and scheduling problem in operating integrated mobility systems

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Keywords: Integrated dial-a-ride problem, Large Neighborhood Search

A trend towards Mobility as a Service (MaaS) is observed in many Western countries. MaaS is a recent technological advancement that transforms mobility systems into more flexible and efficient ones by integrating different transportation modes. In this research, the focus lies on the integration of timetabled public transport (PT) and dial-a-ride (DAR) services allowing passengers to travel by a combination of these two modes. Users submit a single transportation request for their entire trip, indicating their service requirements (e.g., time windows, maximum trip duration, ...). The routes and schedules of the demand-responsive DAR services are planned by a mobility provider. They must be aligned to the public transport timetables to allow efficient transfers and take into account the users' service level by avoiding large detours and long waiting times during transfers.

From the perspective of the mobility provider, the exploitation of such an integrated mobility system leads to challenging routing and scheduling problems on the operational level. The ultimate aim of the mobility provider to is generate efficient real-time solutions in response to all user requests by optimally combining and aligning the available transport modes with each other while minimizing the operational costs and the total trip times of the users. From the users' perspective, it is important that the proposed solutions are of high quality (e.g., attractive travel times) and reliable (e.g., low risk of missed transfers). This quality experience is essential to guarantee a successful implementation of the MaaS concept on a large scale.

Therefore, the main goal of this research is to develop a quick and efficient planning algorithm for integrated mobility systems that responds to all the aforementioned aspects, eventually enabling real-life systems to operate in the most efficient and user-oriented way. However, the academic literature lacks insights in (1) how the operational planning of an integrated mobility system should be designed such that operational efficiency and service quality are optimally balanced and (2) how this planning can dynamically be revised in case of unexpected events, such as delays on the PT network causing missed transfers.

In this talk, the static and deterministic case of the corresponding routing and scheduling problem will first be modelled through a mixed-integer linear programming (MILP) formulation. Second, the design of a Large Neighborhood Search (LNS) framework for this problem will be discussed. To incorporate the trade-off between the operational costs and service level in the optimization process, a tailored scheduling subprocedure is presented which minimizes the sum of the users' trip durations for a given route. We will discuss experiments on small-scale artificial instances by comparing the results obtained from the LNS metaheuristic with the optimal solutions. Finally, the next steps in this research (e.g. incorporation of dynamic events, risk reduction in initial planning) will be discussed.

Shedding light on modal choice: examining the relationship between public lighting and nocturnal mobility

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Keywords: Public lighting; mobility; modal choice

Lighting is an essential aspect of our daily lives, but artificial lighting has received criticism for its negative impact on the environment, wildlife, and health of people [1]. Adequate lighting is crucial for creating a safe environment (in terms of road safety, criminality and feeling of safety), especially when using soft modes of transport like walking or cycling at night. Poor lighting, on the other hand, can make people feel unsafe and uncomfortable, potentially deterring them from using these modes [2, 3].

Our research offers three contributions. Firstly, it identifies the required characteristics of public lighting for safe and acceptable nocturnal mobility. Secondly, it investigates how the night affects modal choices. Thirdly, it assesses citizens' willingness to accept reduced public lighting and how the energy crisis has impacted their judgement.

To gain insights into the mobility patterns of the population in the Walloon region, we conducted two surveys using Qualtrics. The target population for both surveys was individuals aged 16 and above living in the Walloon region. The first survey was administered online from February 16th to March 29th, 2022, resulting in a total of 677 complete responses. The margin of error for the first survey was at most 3.77% with a 95% confidence interval. The second survey was also administered online from 1st October to 15th November 2022, resulting in 807 complete responses. The margin of error for the second survey was calculated to be at most 3.45% with a 95% confidence interval. The collected dataset was analysed using RStudio, and population weights were applied based on three demographic criteria (gender, age, and

province) to ensure that the sample was representative of the Walloon population.

The findings of this study highlight the importance of public lighting in nocturnal mobility and provide insights into the factors influencing citizens' modal choices and acceptable levels of lighting reductions. Citizens are willing to accept reductions in public lighting levels during the night, which could contribute to reducing light pollution and energy consumption. The study also reveals a positive correlation between the energy crisis and citizens' willingness to accept reductions in public lighting levels, highlighting the importance of implementing energy-efficient public lighting systems.

Further research could examine the impact of public lighting on the health of citizens, potential emerging technologies such as smart lighting systems and autonomous vehicles, and the impact of reduced lighting on nocturnal wildlife, light pollution, and carbon emissions.

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River-sea liner shipping service network design: the case study of Danube River and Black Sea

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Keywords: Liner Shipping, Service Network Design, Waterborne transportation

Maritime transportation is one of the oldest forms of human connection in history, and waterborne transport has always played a crucial role in trade and cultural exchanges. Maritime transport carries more than 90 percent of international trade volumes, especially in worldwide logistics networks [3]. Over the past three decades, the amount of containerized cargo has increased by more than 8 percent annually, and in 2017, there were more than 5,150 container boats operating globally [2]. One of the most well known optimization problem in this area is liner shipping network design.

Another recent trend is the design of logistic networks based on the concept of the Physical Internet (PI). In very recent work, [1] propose to design a PI distribution system on a river network. These scheduled transportation lines should be able to satisfy local transportation requests, but also to connect the local market with the major international hubs. This study aims at filling the gap between major maritime hubs and local hubs located on rivers. The main objective is to design transportation lines as well as their frequency between river ports and maritime hubs.

We present a case study in the downstream Danube River and Black Sea region. This region is characterized by an intense traffic, where a part of the ships navigate exclusively on the river network whereas other ships can also navigate on the Black Sea's western shore until major ports like Istanbul or Piraeus.

Given a set of transportation demands, a set of available ships and possible transportation lines, and a set of ports, including transshipment hubs, the goal is to determine the lesat cost set of operating lines as well as their frequency and the fleet used while satisfying the demand and classical logistic constraint related to capacity, and quality of service. We propose a mixed-integer linear programming (MILP) formulation, which is an adaption of the Liner Service Network Design model proposed by [4]. Finally, we present the results of computational experiments and study the impact of several problem features, such as the hubs capacity, the ship size and the

number of transshipments.

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Sustainable multimodal logistics networks: A simulation model for collaborative systems

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Keywords: Multimodal logistic network, Horizontal collaboration, Simulation

The logistics sector is aiming to become more sustainable by reducing its emissions, and horizontal collaboration is seen as a key strategy for achieving this goal (Ambra et al., 2019). However, implementing collaborative systems faces several challenges due to the competitive nature of the transportation sector, including a lack of willingness and trust between different actors. Simulation tools can help address these challenges by assessing the impact of different logistics schemes and supporting the design of collaborative systems (Ferrell et al., 2020; Pan et al., 2019).
This project proposes a simulation model of a large multimodal logistic network that can represent different scenarios in terms of flexibility and collaboration between logistic service providers (LSPs). The model compares different scenarios and examines the impact of increased flexibility and cooperation on operations, looking at the total costs and emissions of the system. The proposed model also estimates the impact on individual players to determine how the gains of collaboration are distributed. This way, it provides insights into the potential benefits and drawbacks of collaboration and supports the design of compensation schemes to encourage LSPs to participate in collaborative systems.
The simulation model represents a regional multimodal network with multiple LSPs, each with its own truck fleet and established contracts with train carriers. The model considers stochastic demand, in which external customers submit freight transportation requests with specific time windows. Then, LSPs make offers to satisfy the request according to their available resources, considering real-time information about the current location and utilization of vehicles, as well as the planned operations for the near future. The cheapest offer is selected and the request is assigned to the corresponding LSP. Heuristic algorithms are used to route the trucks and assign the requests to specific vehicles. The simulation model offers the ability to test different scenarios regarding the level of cooperation between LSPs, comparing competitive

scenarios, where LSPs only use their own resources, to collaborative scenarios, where LSPs can trade services with each other.
The model is tested in a synthetic instance with three LSPs, representing one week of operations with an average of 400 requests per day. The results show that greater flexibility and collaboration in the logistic network led to lower costs for the system overall, with less distance travelled by trucks and a higher share of containers transported by train, indicating a lower environmental impact. However, the gains are not equally distributed when there are significant differences in the relative size of the LSPs. Larger players tend to increase their market share and have a greater increase in profits, while smaller players may even face losses. These findings highlight the need to design compensation schemes that encourage LSPs to participate in collaborative systems.
In conclusion, the logistics sector's efforts towards sustainability and emissions reduction can benefit greatly from the implementation of collaborative systems. The proposed simulation model provides valuable insights into the potential benefits and drawbacks of such systems, and the results indicate that collaboration can lead to lower costs and a lower environmental impact. However, compensation schemes must be designed to ensure that the gains are distributed equitably. Ultimately, the use of simulation tools can help encourage participation in collaborative systems and support the logistics sector in achieving its sustainability goals.

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Hybrid segmentation approaches for supervised learning in R

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Keywords: Machine learning, Segmentation, R

Introduction

Segments or homogeneous groups exist everywhere naturally. In business context, among a group of customers, we can always find segments with distinct characteristics, preferences, needs, and reactions. To maximize the efficiency of business activities, individuals in those segments should be grouped and treated differently. Recent studies have proven that using segmentation approaches for modeling may significantly increase the predictive performance and comprehensibility of the model. In this paper, we introduce a new statistical library for R containing two hybrid segmentation methods for binary classification and uplift modeling.

Methods

Hybrid segmentation is a two stages modeling processing in which individuals are categorized into different segments and are modeled separately [1]. This method significantly increases the predictability and comprehensibility of the building block models.
In addition, hybrid segmentation methods can be applied to various modeling problems as well as data types. In binary classification, we select decision tree (DT) for the segmentation stage and logistic regression (LR) for the modeling stage [2]. Similarly, in uplift modeling, an uplift decision tree (Uplift DT) is used to constuct

segments, while the uplift logistic regression (Uplift LR) handles the modeling step [3]. For that reason, these two machine learning algorithms are named as Logit Leaf Model (LLM) and Uplift Logit Leaf Model (Uplift LLM). Moreover, the same modeling approach can be used to incorporate and detect segments in unstructured textual data [4].

Conclusion

Finally, we benchmark the LLM and Uplift LLM model with theirs building blocks. The result shows that these hybrid models are significantly better in prediction performance, while prodive additional information on the customers' segments.

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Pattern-based time series segmentation

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Keywords: Semantic segmentation, Multivariate time series, Pattern mining

In recent years, the wide availability of low-cost, high resolution sensors has led to a dramatic increase in monitoring capabilities. Across a wide range of application areas, increasingly long sequences of measurements (i.e., time series) are being monitored. The monitored process is typically composed of multiple states. *Time series semantic segmentation* aims at automatically uncovering these hidden states from the time series data in an unsupervised manner [1, 3].

State transitions often do not lead to abrupt changes, but happen gradually. For example, in motion capture analysis, there is a gradual transition from the state *sitting* to the state *standing*, namely *standing up* [2]. State-of-the-art time series semantic segmentation algorithms have only focused on identifying discrete state transitions through change point detection [1, 3]. As noted in [1], detection of gradual changes is "outside the scope of *current* time series segmentation methods".

We propose Pattern-based Time Series Segmentation (PaTSS), a novel, domain-agnostic semantic segmentation algorithm that can learn gradual state transitions in time series data. PaTSS performs a semantic segmentation for gradual state transitions based on an embedding space derived from mined sequential patterns. It achieves this by performing the following steps:

1. Segment the time series using multi-resolution sliding windows, and transform each segment into a symbolic representation. By considering multiple resolutions, PaTSS captures both long and short term behavior.
2. Mine frequent sequential patterns in the symbolic representations, thus learning the frequent shapes and behavior of the time series. For this step, PaTSS leverages the well-established field of frequent pattern mining [4].
3. Embed the time domain using the mined frequent patterns. For each pattern and each time unit, the embedding value is set to the relative support of that pattern if it covers the time unit, and to zero otherwise.
4. Identify the semantic segments which have a similar embedding (and consequently similar behavior) and learn the likelihood of each semantic segment occurring at a certain time.

By learning distributions over the different semantic segments, PaTSS can identify gradual state transitions, namely when the likelihood of some segment decreases while the probability of another one increases.

PaTSS has two major advantages, besides being able to identify gradual state transitions. First, PaTSS can identify reocurring behavior in the time series, because the goal is to group similar behavior. This is in contrast to state-of-the-art semantic segmentation procedures, which separate dissimilar behavior through change point detection. Second, PaTSS uses frequent patterns to embed the time series. This ensures that the decision making process is highly explainable because every decision can be linked to a small set of easy-to-interpret patterns.

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What makes a 0–1 knapsack problem instance hard?

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Keywords: Combinatorial optimization, 0–1 knapsack problem, instance space analysis

Many years of research on the 0-1 knapsack problem has resulted in highly efficient algorithms that are capable of quickly solving numerous large problem instances to optimality. As a result of this success, researchers have become increasingly interested in identifying instances that are challenging to solve to optimality and characterizing what makes them hard. In this work [2], we introduce a new set of features (based on previous work by the authors [1]) and investigate to what extent these features are related to the hardness of a problem instance. Calculating these features requires one to solve hard combinatorial problems. We uncover new structural results that allow us to formulate polynomial and pseudopolynomial time algorithms for solving these problems. The algorithms were implemented and used to calculate the features for two large data sets. We compare our features with existing features from the literature and use these as input for machine learning models that predict the running time of the state-of-the-art 0-1 knapsack solver ***Combo*** [3]. Furthermore, we show that these features can be cheaply approximated at the expense of less accurate running time predictions. We use the instance space analysis methodology to project the problem instances into a two-dimensional space and identify regions where the hard instances are located.
Full paper: https://arxiv.org/abs/2211.09665

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The complexity of computing a robust MDP policy

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Keywords: Complexity theory, Robust MDPs, Robust optimization

Introduction

Markov decision processes (MDPs), also referred to as stochastic dynamic programming, are models for sequential decision making when outcomes are uncertain. They have become an important tool for optimization under uncertainty in operations research and have applications in diverse fields. In practice, often only limited information is available about the parameters of an MDP such as the rewards r or the transition probabilities P. It is hard to precisely assess the true value of these uncertain parameters from noisy data and furthermore, they may change during the execution of a policy. The performance of policies may deteriorate significantly due to the variation in transition probabilities [1]. In this paper, we focus on the variation in r and P.

To cope with this lack of reliable information, we consider the robust MDP setting where we model the uncertainty in transition probabilities as an adversarial selection from a non-convex uncertainty set and the number of deviations from the nominal value is bounded by a global adversary budget k. Our goal is to find a policy that maximizes the worst-case expected reward over the choices of the uncertain parameter from the uncertainty set. Our new model is motivated by so-called network interdiction games in which an adversary called "the interdictor" tries to inhibit the operability of a network by modifying a limited number of its links. Most previous studies of robustness for MDPs restrict themselves to the assumption that uncertainties among different states are independent, also known as the "rectangularity condition" in [3], which makes finding an optimal robust policy computationally tractable. However, such a condition leads to overly conservative solutions as it essentially assumes that all transition probabilities may take their worst possible realization simultaneously, a pessimistic scenario that rarely happens in practice. The literature on robust optimization for MDPs that considers coupled uncertainties is sparse. [1] propose k-rectangularity that encodes the coupling of uncertainty among different states as an integer between 1 and k, which is closely related to this paper. However, they undertake a history-dependent uncertainty model to provide a tractable solution and they also assume that the parameter realization is observable

and reckoned by the decision maker. In contrast, our model is fully Markovian, i.e., both the actions chosen by the decision maker and the uncertainty realization chosen by the adversary are history-independent. The adversarial model we propose allows couplings between transitions across different states and actions that naturally arise in practice and therefore enables a less conservative solution.

Methodology and Results

We study our robust MDP model in the context of an interdiction game involving two players and provide the definition of the Robust MDP Policy problem. The decision maker aims to maximize the expected total reward over a finite or infinite horizon while the interdictor modifies the transition kernels to minimize the total reward. The interdictor is also given an integer interdiction budget k, which specifies how many state-action pairs can be modified by the interdictor. This global budget in our model is the main difference to previous robust MDP models in the literature. It provides a flexible way to control the conservativeness of robust MDPs.
We firstly show that the Robust MDP Policy problem is already NP-hard even when the interdictor can only modify the reward for one terminal state, based on a reduction from the 3-Partition problem. As our main result, we then prove Σ_2^p-hardness of the problem when k is a part of the input. This result indicates that the problem is unlikely to admit not only efficient algorithms, but even compact (i.e., polynomially sized) ILP formulations.
We further investigate the approximability of the problem. Using two distinct reductions, we show that, unless $P = NP$, the problem does not admit constant-factor approximations even in the following two special cases: (i) in infinite-horizon MDPs where the interdictor can modify only a single reward, (ii) in finite-horizon MDPs where the interdictor can modify the transition probabilities of at most two state-action pairs. On the positive side, however, we devise a constant-factor approximation for the case that the MDP consists of two stages and the interdictor can modify at most one reward. To obtain this result, we combine Shmoys & Tardos' rounding algorithm for the generalized assignment problem [2] with dynamic program for the multiple-choice knapsack problem. Identifying further subclasses of nonrectangular uncertainty sets for which the Robust MDP Policy problem remains at least approximately solvable is an interesting direction of further research.

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Scheduling the Belgian soccer leagues

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Keywords: Sports timetabling, Benders' decomposition, multi-league

Every sports league needs a schedule of play, which determines when and where each match will be played (according to a given competition format). A good schedule is important, since it has an effect on public attendance, commercial interests, as well as security and the cost of policing, and moreover, it impacts the fairness and outcome of the competition. The complexity of a sports scheduling problem depends on what should be taken into account. Generating a schedule where each team plays against each other team an equal number of times, and at most once on any given matchday is a simple task (see e.g. [2]). However, as more constraints and considerations have to be taken into account (see [7] for an overview), sports scheduling can quickly become a massive challenge.

We have been assisting the Belgian Pro League with scheduling their soccer competition since 2006. While originally, we only scheduled the highest professional leagues [3], not much later, we were also called upon for the second professional league, and the first amateur league. For a long time, we applied a hierarchical approach, scheduling these leagues one by one, in order of their importance. Furthermore, apart from an occasional pair of teams sharing the same infrastructure or police zone, the link between these leagues was not very strong. Over the years, however, the number of leagues that we scheduled kept increasing. Indeed, after including the lower amateur leagues, we found ourselves scheduling over 10 Belgian soccer leagues in season 2022-23. At the same time, the organization of the competition changed radically, with the integration of the under-23 (U23) teams of the professional clubs into the regular leagues, instead of clustering them into a separate U23 competition. Indeed, apart from the top league, all lower leagues now include 2 to 4 such U23 teams. Moreover, due to more stringent venue requirements in effect in their new leagues, most of these U23 teams now share their venue with their professional team. Hence, an intricate entaglement of all leagues arises, since such U23 teams and their

professional counterparts cannot both play a home game on the same matchday. The resulting scheduling problem is to be seen as a multi-league sports scheduling problem (see e.g. [1]), where several leagues need to be scheduled simultaneously, and a hierarchical approach no longer works.

We describe a decomposed approach where we first schedule the so-called home-away patterns of the league (indicating for each team when it plays at home, and when away). The second phase consists of scheduling the opponents for each team, based on the home-away patterns. While this decomposition is a common strategy in sports scheduling (see e.g. [5]), its application in a multi-league context is more recent. Contrary to [1] and [4], however, we do not use the same set of home-away patterns for each league, but instead design a set of home-away patterns for each league, in a way that these sets are compatible and yield promising results for the second phase. We do this by means of a Benders' decomposition approach, inspired by [6], which allows us to efficiently backtrack between both phases. The resulting solution can then further be refined for each of the leagues, without creating conflicts with other leagues.

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A parallel-machine learning framework to tune metaheuristics for advanced manufacturing scheduling problems

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Keywords: Automatic tuning, Manufacturing scheduling, Parallel computing

Scheduling manufacturing processes is crucial to guarantee maximum efficiency of operations, efficient usage of available resources, and reduced costs. A common approach to solve this problem is using Meta-heuristics (MH), which have become a *de facto* approach to find approximate solutions for complex scheduling problems. However, since the quality of solutions provided by these methods is highly sensitive to the value of their parameters, tuning parameters is a key and challenging step to guarantee a good performance of MHs.
Tuning MHs is not a trivial procedure since it is in turn dependent on the complexity of the problem at hand and the available time to perform such procedure. In the context of real-world manufacturing processes, the specific characteristics of such processes give place to complex scheduling cases, which turn MHs into expensive-to-evaluate functions for candidate settings needing to be tested. Such characteristics include a continuously growing number of product types, the interaction of semi-finished goods and operations in their respective bills of material, as well as the specific constraints of manufacturing operations that need to be balanced. The fact that MHs become expensive-to-evaluate functions impose challenges to both online and offline tuning. In the first case, finding taylor-made parameter values every time a case needs to be scheduled becomes challenging because in manufacturing, the scheduling task is expected to be performed in short time (minutes to few hours) to start the production stage and react to unexpected changes in the manufacturing environment. Thus the tuning budget is very constrained. In the second case, finding a single well-performing parameter set that generalizes well for new cases becomes challenging. Indeed, despite having a larger tuning budget in the training phase, most MHs used to solve complex manufacturing scheduling problems are stochastic.

This means that it is necessary to perform more function evaluations to cope with the uncertainties of the cost function and gather enough statistical information in favor or against candidate settings. To this end, the high complexity of manufacturing processes is counteracting.
In this talk, we propose a Bayesian-Optimization (BO)-based framework supported by parallel computing techniques to perform MH's tuning. BO is a sequential-design strategy used to optimize expensive-to-evaluate functions. It performs a sequential optimization of a cheap-to-evaluate probabilistic surrogate model whose believes are updated as data is gathered in the form of limited evaluations of the expensive function. The proposed framework is expected to be able to capture the specificity of manufacturing processes in a training phase by learning the impact of MH's parameters on the business key performance indicators. By doing so, the framework can be used to find a near-optimal parameter setting able to produce efficient schedules for new cases once it is trained. Thus, instead of tuning the MH's parameters every time a case needs to be scheduled, a fixed well-performing setting can be used to obtain timely schedules. The framework uses parallelism to support multiple sampling at each iteration of BO. The proposed algorithm is intended to be evaluated with the base model of a Belgian company dedicated to perform Advanced Planning and Scheduling using MHs. The comparison will be performed over a set of cases of sales orders for a real manufacturing process using a Genetic Algorithm as the underlying MH. The proposed algorithm is expected to outperform the solutions provided by the base model of the company demonstrating good generalization capabilities for new cases of the manufacturing process. The expected results would demonstrate the potentiality of the proposed framework as a managerial tool that can be integrated with existing Advanced-Planning-and-Scheduling software that use MHs as their underlying models.

Strategic process design optimization: State of the art analysis

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Keywords: Strategic process design, Assembly line feeding, Robust optimization

In contemporary times, assembly environments are becoming increasingly complicated due to rising customer demands for customized products, leading to an increase in the variety of required parts. Literature has already extensively investigated the tactical implications of this trend. The introduction of supermarkets has facilitated the repackaging of parts into smaller boxes or kits. This, in combination with the identification of five different assembly line feeding policies, has led to a tailored approach for each part and a reduction in the resulting total costs. Additionally, the balancing of the assembly line, the optimal routes of vehicles, and the impact of the entire process on the assembly workers' ergonomics have been studied in the past. However, all these studies have adopted a tactical viewpoint and relate to brownfield situations. The strategic environment of these studies is largely predetermined representing companies with limited options to change certain factors in the near future. The assembly plant's layout, the location, size and capacity of the supermarkets and the type and quantity of available vehicles, as well as the assignment of vehicles to part flows are all assumed to be fixed.

In the future, it might be interesting to design a strategic assembly line feeding problem starting from a greenfield situation where all of these factors are still to be decided on. Although current literature has examined some of these decisions separately, a comprehensive model that considers all of them at once is yet to be developed. Companies installing a new production site or redesigning their current site could benefit from this global type of model.

To establish a starting point for further research, we review existing literature on strategic assembly process design and related strategic problems that could provide valuable insights into the problem at hand. A related strategic problem is the facility location problem, as the accompanying global location-allocation problem also consists of a strategic and a tactical part, similar to the strategic assembly process design problem and the tactical assembly line feeding problem.

Given the strategic viewpoint of our research and the definitive nature of the decisions involved, the problem requires solutions that provide good and relatively stable results in various future scenarios. Hence, we focus on robust approaches to tackle strategic problems during our literature review. Different approaches could be applied such as stochastic programming or possibilistic/fuzzy programming. We summarize the existing literature and identify gaps and opportunities that might lead to interesting future research.

A case study for transportation optimization on assembly line feeding

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Keywords: Optimization, Manufacturing, Decision making

In recent times, increasingly many part variants require assembling at the assembly line due to the continuous rise in customers' individualized demands. To this end, challenges arising from part feeding to the border of line (BoL) i.e., the area next to each assembly station designated for part storage, remains a valid problem. More precisely, the current problem is concerned with how parts can be delivered to the BoL of a machinery manufacturing company in a prompt and cost-efficient manner. Since various models exist for the assembly line feeding problem, this study aims to apply an existing model that integrates assembly line feeding and vehicle type decisions to the company's specific requirements [1]. Consequently, cost-efficient intra-logistics flow, prompt delivery of parts to the BoL, and the usage of the most efficient feeding policy for every part will be achieved.

Different researchers have studied the assembly line feeding problem (ALFP), e.g., [2] proposed an optimization model that minimizes total feeding costs when deciding the best feeding policy between stationary kitting and line stocking for every part, [3] proposed an optimization model, based on a real-life case study, that determines the most efficient feeding policy among sequencing, traveling kitting and line stocking. Although researchers have studied the ALFP concretely, the integration of transportation decisions has not been integrated into line feeding decisions until recently when [1] developed an optimization model that simultaneously assigns every part to a feeding policy and a vehicle type with the aim of minimizing the overall feeding and acquisition costs. Even though the previous work on the integration of assembly line feeding and vehicle type selection decisions further led to overall cost savings, that study is based on artificial problem instances. By contrast, other studies based on real-life case study do not incorporate vehicle type selection decisions into their framework [3]. This study, however, validates a mixed integer linear programming model that incorporate vehicle type selection decisions into assembly line feeding, by a real-life case study.

The mixed integer programming model, which is an extension of the model proposed by [1], simultaneously assigns every part to one of twelve feeding policies, i.e., line stocking, boxed supply (small, medium, large), sequencing, box picking, pallet picking, (type 1, type 2, type 3) stationary kitting, (type 1 and type 2) traveling kitting, and a vehicle type, i.e., AGVs, forklifts, tow trains or manual carts, for transporting every part. The extended model minimizes total material handling costs incurred through four subprocesses: (*i*) replenishment of the preparation areas or supermarket; (*ii*) preparation; (*iii*) transportation to the line; and (*iv*) usage at the line. Since two automated warehouses and a manual warehouse are in scope of this study, the preparation process at the automated warehouses is done in a picker-to-part manner, i.e., from any automated warehouse, parts are conveyed to the corresponding preparation area through a conveyor. Consequently, the preparation cost for these parts factors in the waiting time incurred. Furthermore, for every vehicle type used, an operating (replenishment or transportation) and investment cost is incurred. The model is solved using Gurobi 9. According to the results, in terms of cost savings, the optimal assignment and other cases, which are of interest to the company, outperform the company's current assignment by 56% and at least 23% of the total costs of the current assignment, respectively. These results will be presented.

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Design of reconfigurable cellular manufacturing systems with alternative routing

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Keywords: reconfigurable cellular manufacturing systems, tactical planning, integer programming

Introduction Reconfigurable Manufacturing Systems (RMS) have been proposed to achieve a balance between the efficiency of Dedicated Manufacturing Systems (DMS) and the flexibility of Flexible Manufacturing Systems (FMS) as a response to the changing market trends. The main objective of RMS is to adapt to demand volatility and changes in product functionality while minimizing associated costs and efforts. This is achieved by designing a modular system around a part family so that it can be reconfigured to meet different part requirements and still maintain high efficiency.[1]
Cellular Manufacturing Systems (CMS) are based on the concept of group technology, which aims to increase productivity by grouping common principles, problems, and tasks.[2] Similarly, Reconfigurable Cellular Manufacturing Systems (RCMS) are defined as CMSs in which the cells are comprised of machines that can be reconfigured to alter their functionality.[3] Our study presents an Integer Programming approach to address a multi-period planning problem for Reconfigurable Cellular Manufacturing Systems. The objective is to optimize resource allocation, reconfiguration, and part routing decisions concurrently while minimizing total cost and ensuring that the demand for parts is met during each period.

Problem Definition The system in focus consists of several possible cell locations where a limited number of machines can be grouped and allocated at the beginning of the planning horizon. Each machine can perform a subset of required operations

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for the part family when combined with different modules. Therefore, the modules have to be allocated to the machines at the beginning of the planning horizon. However, each machine has a limited capacity to store modules, and a module is suitable only for a subset of machines. In each period, one of the allocated modules at each machine is selected and used to perform one of the required operations. If different modules are used at a machine during consecutive periods, it is assumed that the reconfiguration takes place between these periods without affecting available machining time, but at a certain cost. Moreover, each module-machine combination can perform an operation at a deterministic processing cost and time, depending on the parts and operation type that is performed. Furthermore, an additional cost incurs at the beginning of the planning horizon for each allocated module, machine, and cell. Finally, since the aim is to improve efficiency and productivity by grouping parts and machines into cells, inter-cellular movements are penalized, but not forbidden to keep the system more flexible. Hence, the objective of the problem is to meet the demand for the parts in each period by allocating the resources, planning reconfiguration with the modules, and routing the parts while minimizing the total cost which includes processing, reconfiguration, allocation, and inter-cellular transportation costs.

Solution Approach The problem is formulated as an Integer Programming problem. Three types of decision variables are defined for part routing, resource allocation, and reconfiguration. The integer routing variables represent the number of parts following each possible route which are generated along with their inter-cellular transportation and processing costs and resource requirements in a pre-processing step. The binary allocation variables represent the allocation of resources, such as $YMachine_{m,c} = 1$ if machine m is allocated to cell c, and for the used modules in each period, such as $Z^t_{s,m,c}$=1 if module s is used at machine m in cell c during period t. In addition, four types of constraints are defined: allocation constraints to apply logical rules for the system and resources, reconfiguration constraints to ensure that reconfiguration variables take appropriate values depending on the module usage, demand constraints to guarantee that the demand for parts is met in each period by following one or more routes, and availability constraints to avoid exceeding the capacity of the resources that are required by the routes followed. After the problem is modeled as an Integer Programming problem, it is solved using Gurobi.

Conclusions and Future Work The study presents an IP model to solve a planning problem for the Reconfigurable Cellular Manufacturing Systems. Using Gurobi, a number of small instances are solved optimally within feasible amount of time. However, for larger instances, this is no longer the case as the number of variables grow exponentially depending on the number of operations required and the number of suitable module-machine-cell combinations for each operation. Hence, heuristic approaches will be developed to solve the larger instances more efficiently, as our next step. Furthermore, it is planned to extend the problem by considering resource repositioning and in-period machine reconfiguration, to fully utilize the flexibility of the Reconfigurable Manufacturing Systems.

A classifier approach for probabilistic forecasting in transportation planning

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Keywords: Forecasting, Transportation Planning, Stochastic Demand

Introduction and Problem Description

The freight transportation industry in France is becoming highly competitive, complex, and is currently facing many tensions. Environmental issues, energy prices, and the difficulty in recruiting drivers have accelerated the practice of pooling transport between several producers with common customers.
In the ultra-fresh product sector, producers are required to market products that must be consumed in a timely manner. Additionally, customers usually place their orders for next-day or even same-day delivery which makes for tight logistics flows. However, producers still need to book vehicles days before the date of dispatch in order to have sufficient capacity available and to let the carriers organize themselves.
The implementation of a shared ecosystem in this type of sector requires the coordination of transport planning when **customer demand is not known with certainty.** To address this issue, it becomes necessary to develop data-based decision-making tools for freight transportation under uncertainty. This problem has been addressed in [1]. The authors propose a two-stage stochastic model where the objective is to minimize the total expected cost of transporting all customers' orders while the transportation plans needs to be done one week in advance.
To model the decision making under uncertainty, the use of scenarios, where customers have varying values of demand, and its each own probability, is one of the most viable option. This decision making process also requires the **development of accurate forecasting models for demand planning**, since forecasting will produce the data to prepare and simulate the scenarios. Furthermore, poor quality predictions could lead to various problems such as shortages, over-stocks, delays, bullwhip effects, and lost customers [2]. Traditional point forecasting models do not capture the full range of possible outcomes (i.e. scenarios). Therefore, a method to provide probabilistic predictions of the set of possible outcomes might be adopted to build a stochastic transportation optimization model. Thus, probabilistic forecasting can be employed within this context.
Methods including time series or regression-based models and machine learning are able to generate probabilistic forecasts. But most of them either only provide the range of the

possible outcomes or the probability of a certain forecast results, not both. To accommodate both variables, confidence intervals and probability distributions can be utilized. Conditional probability is proven to be effective in integrating these two inputs to provide probabilistic insights [3]. Hence, we aim to develop an algorithm to forecast stochastic customers' demand through conditional probability as the end product. This algorithm ought to work by predicting the likely values and associated probabilities of the actual demand based on the known forecast. This will later be used to generate better scenarios for the stochastic optimization model in [1].

Methods and Findings

We perform Exploratory Data Analysis (EDA) on 7 daily demand time series data sets over a period of 10 months provided by ultra-fresh companies. Each data set contains 2 variables: 1) actual historical demand, and 2) existing forecast of demand. The EDA shows differences in mean and standard deviation and also highlights different time series patterns for each client. A feature selection process is also performed to take into account the time series characteristics (i.e. day of the week, month). Through seasonality analysis, the data reveals a 7-day pattern. Furthermore, from the feature extraction, the day of the week produces the highest importance factor, reaching around 80 percent of importance, while other features have negligible importance value. Thus, we split each data based on the day of the week and analyze the probability distribution within each group of days separately. We use the prediction intervals approach and combine it with the probability distribution of both the actual and forecast data. Then, it is simplified into discrete histogram bins with their respective probabilities. The bins can be set to accommodate the desired number of scenarios for the optimization model. The algorithm is trained to predict the bin class of the actual demand based on the bin class of the forecast for each day of the week and for each client. To compare the results of the predictions, multi-class classification methods who inquire similar approach are also employed (Decision Tree, Random Forest, Naive Bayes, K-Nearest Neighbour, and Support Vector Machine). Metrics including accuracy and confusion matrix are computed to evaluate the performance of all models and they provide at least 60-percent accuracy for all the trained data sets. These preliminary results are deemed to be enough to generate the probabilistic scenarios, considering the limited data and forecasting algorithm.
Overall, modeling the probability of the demand is a crucial aspect in this step, which can provide valuable inputs for the optimization of transportation plans under stochastic demand in future works. This research is carried out in the framework of CRC Lab, a joint laboratory between IMT Atlantique and CRC Services company.

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Using adaptive loss balancing to boost improvements in forecast stability

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Keywords: Time Series Forecasting, Forecast Instability, Deep Learning

Forecast (in)stability, defined in this work in terms of the variability in forecasts for a specific time period, is caused by updating the forecast for this time period when new observations become available, i.e., as time passes. Forecast instabilities possibly cause costly changes to plans that were devised with the forecasts as inputs. For instance, in supply chain management, demand forecast instabilities potentially lead to revisions of supply plans, resulting in excess costs. However, these extra costs are generally considered to be outweighed by the benefits of forecast updating in terms of forecast accuracy improvements. Therefore, point forecast generation and evaluation traditionally focus on forecast accuracy.
In [5], a methodology is presented that allows optimizing global deep learning models for univariate time series point forecasting from both a traditional forecast accuracy perspective as well as a forecast stability perspective. The key element of the proposed methodology is the use of a composite loss function consisting of both a forecast error and forecast instability component. [5] extend the N-BEATS deep learning architecture [4] to enable the utilization of this composite loss function and show that the proposed extension results in more stable forecasts without causing a loss in forecast accuracy for the publicly available M3 and M4 competition data sets. In a supply chain management context, more stable demand forecasts lead to fewer (and smaller) supply chain plan changes, and thus lower supply chain costs. However, the experimental results in [5] show that the proposed extension allows improving both forecast stability and forecast accuracy compared to the original N-BEATS model, which indicates that the forecast instability loss component can also be used as a time-series-specific regularization mechanism. Therefore, including a forecast instability component in the loss function can be useful for forecasting applications in general, in

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addition to settings in which forecasts are updated and forecast instability comes with certain costs.

To improve the forecast stability of global deep learning models for univariate time series point forecasting, the methodology proposed in [5] relies on a static hyperparameter that controls the extent to which the forecasts produced by the network are influenced by the forecast instability component. However, because gradient descent is used to optimize the neural network, adaptive weighting schemes could alternatively be used to dynamically balance the two loss components that constitute the composite loss function, i.e., forecast error and forecast instability. Since a flat (mean or zero) forecast is optimal from a stability perspective but (usually) not from an accuracy perspective, using varying weights for the different loss components across training iterations appears intuitively appealing as it seems sensible to include forecast instability in the optimization only after a reasonable forecast accuracy has been achieved.

In this work, we investigate whether it is possible to further improve forecast stability (and forecast accuracy) of global deep learning models for univariate time series point forecasting by combining the methodology presented in [5] with adaptive loss balancing. We empirically assess the performance and potential added value of different adaptive loss balancing strategies, including GradNorm [2], Gradient Cosine Similarity [1], and Random Loss Weighting [3], on the publicly available M3 and M4 monthly data sets. Our results show that it is possible to further improve forecast stability without harming forecast accuracy by using adaptive loss balancing instead of static loss weights. However, this observation does not hold true for all adaptive loss balancing strategies included in this study as some strategies result in a significant improvement in forecast stability at the cost of a deterioration in forecast accuracy. Therefore, we can conclude that adaptive loss balancing is useful for the problem tackled in this work, but that the adopted strategy should be selected carefully.

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Validation set selection in predictive process monitoring

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Keywords: Process Mining, Predictive Process Monitoring, LSTM

Process mining is a discipline consisting of techniques that can be used to discover, monitor and optimize business processes using recorded event data. Within this field, predictive process monitoring concerns itself with predicting different aspects of ongoing cases of such processes. These aspects can be remaining time, outcomes, next event, or even the full remaining case suffix. In recent years there has been a surge in research discussing the use of machine and deep learning-based approaches to predictive modeling, especially the long short-term memory (LSTM) recurrent neural networks garnering a lot of attention [1]. Despite these models displaying favorable results for multiple predictive tasks, no guarantees can be made about whether these models effectively learn the underlying process structure. This opens the question of whether these models can actually "learn" process behavior, in the similar way humans process modelers would do, from (possibly incomplete) event logs, displaying not all behavior allowed by the model.

In earlier work, we have designed and presented a framework to assess a next event prediction model's capability to generalize and understand process model structure [2, 3]. This framework uses variant-based resampling and custom metrics for fitness, precision, and generalization. Event logs with all possible control-flow variants are used, and a fraction of these variants are removed from the training log to test the LSTM's ability to learn the full process structure. An LSTM is trained on next event prediction using this reduced training set, and a simulated log is created by sampling from the LSTM's predictions. Fitness, precision, and generalization are then scored using the simulated log, training samples, and test set (variants removed from the training set). Fitness measures the presence of training samples in the simulated log, precision measures the occurrence of simulated variants in the original event log, and generalization measures the occurrence of holdout test samples in the simulated log. It was shown that LSTMs struggle to learn process model structure when hyperparameters are determined by optimizing the next event prediction accuracy on a regular (not variant-based) sampled validation set. The problem can be mitigated by properly tuning the hyperparameters to include anti-overfitting measures.

This study introduces different novel contributions to this existing research. Firstly, the impact of diverse validation set sampling techniques on the predictive models' ability to comprehend underlying processes is investigated. This investigation includes the application of variant-based resampling approaches and hopes to provide practical recommendations for training predictive process monitoring models. Secondly, the influence of various hyperparameters and early stopping on the aforementioned metrics is also investigated. Additionally, models of different complexities are tested to further investigate the limits of, even properly tuned, models. Next to this, recreate a setup in which the end-user is only provided with a sample event log, not including all behavior allowed in the true process, to train and evaluate its model. To generate this sample event log, a large event log is played out from a process model, which is referred to as the *super log*. Event log samples of varying sizes are subsequently extracted from this *super log*. Similar to the previous approach, the sampled event log is partitioned, and a classifier is trained and simulated to determine fitness, precision, and generalization scores. Moreover, a supplementary set of metrics can be computed by employing the simulated log and the *super log*. *Super precision* measures the accuracy of the model when utilizing the complete *super log* instead of only the sampled event log variants and *super generalization* measures to what extent the variants present in the *super log*, but not in the sampled event log, are present in the simulated log. This allows us to investigate to the importance of event log completeness to the classifier's abilities to learn the underlying process.

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Unit commitment problem with the integration of local energy communities

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With the rise of renewable energy, collective organizations such as Local Energy Communities (LECs) play a key role in the transition to more sustainable energy generation. However, from the point of view of the Distribution System Operators (DSOs) the production of energy at minimum cost is still a topic of interest. For the last five decades, the Unit Commitment (UC) problem is one of the tools that have been used to optimize energy generation, either with or without the incorporation of Renewable Energy Sources.

In this work, the UC problem is extended to a LEC schema. For modeling purposes, LECs are considered as sets of consumers and prosumers with uncertain RES availability and uncertain power loads. The objective is to minimize the total operation costs over a time horizon. Additional features such as power storage and energy sharing among members of a LEC are also considered and evaluated using benchmark instances.

Mixed integer non-linear methods for supporting operations of district heating and cooling networks

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Keywords: DHC operations, MINLP, heuristic

Introduction

Since 2016, the European Commission acknowledges the potential of district heating and cooling (DHC) networks and provides guidelines for reducing the ecological impact of heating and cooling [1]. The EU notably underlines that 'heating and cooling consume half of EU's energy and much of it is wasted' and that '75% of the fuel it uses still comes from fossil fuels' [1]. Decarbonizing the heating and cooling sector appears huge and central for the targets set by the EU. Nevertheless, the report also insists on the existing assets and technology to be used to rapidly reduce carbon emissions: 'A smarter and more sustainable use of heating and cooling is within reach as the technology is available' [1].
In this context, a web-based optimization software, called NEMO, has been developed by Engie Digital to optimize the operations of existing DHC networks. NEMO delivers cost effective and sustainable dispatches for DHC network operations: the solutions returned from the software ensures total system energy efficiency, savings of primary energy and CO2 emissions target.
In this work, we present the general optimization problem solved by NEMO, hints about the solution methods implemented and some insights to show how it is used by operational and engineering teams.

Problem description

The DHC dispatch problem consists in ensuring the supply of heat and/or cold power to customers while minimizing the cost of primary energy. This task can be seen as a unit commitment problem: the planning of the plants has to be done on a certain time horizon while respecting several technical and operational constraints on the network.
The cost of a certain solution depends on several variables such as:

- the plants' power production,
- pumps' flow rates and differential pressures,
- the injection temperature at each departure,

- the storage strategy.

A large range of constraints are considered when operating a DHC:

- Network constraints: pressure drops, heat losses, valve and regulator configurations etc.
- Technical constraints: power ramp-up and down, maintenance planning, unavailability.
- Renewable constraints: Annual renewable ratio, CO2 emitted.
- Long-term gas/fuel contracts.
- Clients' constraints: min/max supply temperature, minimum inlet pressure.

This problem is a highly non linear mixed-integer problem that has temporal coupling. The non-linearities come from the inherent physics of a DHC network and some examples are the following:

- The thermal power production of a plant is proportional to the product of the mass flow rate and the delta temperature of the plant:

$$P_{thermal} \propto \dot{m} \cdot (T_{in} - T_{out})$$

- The pressure difference on a line l is quadratically proportional to the mass flow in the line:

$$\Delta P_l \propto Q_l^2$$

The binary variables come mainly from the unit commitment hidden behind the planning of the units.

Solution method and perspectives

Our approach for solving this complex problem implements an iterative process which relies on:

- a rolling approach,
- linear approximations,
- decomposition methods.

We will show performance results of the approach. We will also share on an another important aspect for industry: how optimization results are used by practitioners and the importance of displaying and understanding the dispatches obtained by an optimization methodology.

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Mixed integer programming for gas and power portfolio management

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Keywords: portfolio optimization, MIP

Introduction

Within the Advanced Analytics department of ENGIE Impact, we leverage our skills in Operational Research to design and develop digital tools to help clients addressing complex industrial issues in the energy sector. The management of power and gas assets is one of them as it includes technical, supply, and ancillary services challenges. In addition, the increasing need for electricity and the gas supply troubles stress the importance of an effective portfolio management.
In this context, PoweredPegase - an optimization tool we develop for internal entities - helps optimizing the management of a portfolio of gas and power assets given the demand and the commodities prices.
In this work, we give a general presentation of PoweredPegase, highlight some modeling challenges and provide insights on its usage and performance.

Modeling gas and power assets

PoweredPegase problem is a mixed integer programming problem suited for both gas and power assets modeling. It is a profit and loss (P&L) minimization problem that ensures to respect technical and operational constraints over different time horizons. It offers an accurate modeling of power and gas markets including on the power side:

- Technical constraints on power assets: ramping, minimum uptime and downtime, minimum and maximum power, start types, etc.
- Power markets liquidities and prices
- Reserve markets
- Fuel consumption
- Hydro assets

And on the gas side:

- Network: nodes and pipes

- Gas markets
- Storages
- Long-term contracts

The problem is a mixed integer problem that has temporal coupling and portfolio constraints. For power assets, binary variables are required to model ancillary constraints and select the start types. There are also binary variables to accurately take into account injection and withdrawal behaviours of storages. We also use smart linearization and approximation techniques to take into account non-convex behaviors in our tool such as withdrawal/injection curves and heat rate curves.

Usages and perspectives

PoweredPegase provides optimal dispatch of power assets and strategies of gas storages and contracts. These outputs are currently used to:

- Support medium term operational decisions
- Support to financial decisions typically hedging studies
- Valuate portfolios (what-if analysis)
- Prevision of portfolio operation (production, revenues...)

The current trend is an increasing use of PoweredPegase tool for the short term operational and financial decisions. This comes with challenges about modeling (financial options to be added) and performance (finer time discretization) .

Leveraging government mobility data to design a charging station network in Santiago, Chile

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Keywords: Electromobility; Mobility Data; Charging Network

The Chilean government is promoting electromobility, particularly in big cities, as the Metropolitan area of Santiago. To facilitate the adoption of electric vehicles, it is crucial to establish a network of charging stations that can cater to the needs of drivers. To enable drivers to charge their electric vehicles near their homes or at their trip destinations, the analysis of the government's mobility data provides the information necessary to create an origin-destination matrix of the journeys made by car by the citizens. This matrix helps identify the key municipalities that serve as origin and destination points for most journeys made by car. By identifying these key areas, it becomes possible to strategically plan the placement of charging stations in locations such as workplaces, shopping malls, theaters, and restaurants that are frequented by people.

Designing a charging station network can be performed thanks to covering location problems. A facility, a charging station, is said to cover a demand node if it is located within a pre-defined distance threshold of the node. This threshold is commonly known as the coverage radius and plays a crucial role in determining the problem's solution. Therefore, choosing an appropriate coverage radius is an essential step in solving the covering location problem: a very large radius of action means that vehicles would have to drive a longer distance to a charging point, while a very

small radius means that many charging facilities would have to be set up to meet the demand, so different alternatives are tested and the results are compared. In the Set Covering Location Problem (SCLP), the objective is to locate the minimum number of facilities within a set of feasible locations required to cover all of the demand nodes. To give the model as much freedom as possible, a set of regularly spaced points in Santiago is considered as a set of feasible locations. An underlying assumption of the SCLP is that all of the demand nodes must be covered. However, charging stations are expensive and a budget does exist. The objective is to locate a predetermined number of charging stations in such a way as to maximize the demand that is covered. The maximal covering location problem (MCLP) is typically applied when there are limited resources or budgets to cover all demand nodes.
Our contribution is twofold. Firstly, we have analyzed the government's mobility data to identify the potential demand for charging stations in each area. This analysis has helped us to understand the travel patterns of citizens and to determine the importance of each municipality as a point of origin and destination. Secondly, we have used this information to develop a maximum coverage model that optimizes the location of charging stations while satisfying global budget constraints.

Robust alternative fuel refueling station location problem with routing under decision-dependent flow uncertainty

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Introduction

Transportation is heavily dependent on fossil fuels. Using alternative fuel vehicles is a solution to break the transportation sector's reliance on consuming fossil fuels. The lack of alternative fuel station (AFS) infrastructure and the rather limited range of alternative fuel vehicles (AFVs) are two significant obstacles that are slowing down the introduction of AFVs. In this regard, the refueling station location problem (RSLP) has recently started to be studied in the literature. In the RSLP, the AFSs are located on the drivers' predetermined paths, which are usually the shortest paths. Since the drivers may tolerate deviating from their paths to refuel their vehicles, the RSLP with routing (RSLP-R) extends the RSLP and determines the locations of stations and routes of drivers simultaneously.

It is likely to observe uncertainties in the flows because the rollout of AFVs and the development of the AFS network are still at their initial stages. Moreover, the statistical data shows that the number of AFSs has a significant impact on the number of AFVs. It is thus important to consider that the availability of AFSs in the neighborhood affects the proliferation of AFVs during the development of infrastructure.

In this study, we incorporate robustness and decision-dependency into the problem and introduce the robust RSLP-R under decision-dependent polyhedral vehicle flow uncertainty. We derive mathematical programming formulations and propose a Benders reformulation and a branch-and-cut algorithm for the reformulation. We perform the following computational experiments: We first compare the performances of the proposed mathematical models and the Benders reformulation. Then, we investigate the changes in station locations and total covered flows when the optimal solutions of the deterministic, robust and decision-dependent robust problems are employed. We observe, under different parameter settings, that recognizing the uncertainty in flows and the decision-dependency of uncertain flow realizations may lead to significant gains in the total AFV flows covered.

Problem Definition and Solution Methods

The RSLP-R is defined on a road network and aims to maximize the total amount of AFV flows that can be refueled by locating a predetermined number of AFSs on the network by considering the willingness of drivers to deviate from their shortest paths to refuel their vehicles as well as the limited range of the vehicles. We use the deterministic problem introduced by [1] and introduce our flow uncertainty set using the hybrid model ([3]). The hybrid model comprises a hose model and an interval model. We define the hybrid uncertainty set of the vehicle flows under the impact of station location decisions. We suppose that, when a new station is opened, vehicle flows in the neighborhood increase because the drivers will be more willing to use AFVs if there are AFSs nearby. We derive two mathematical programming formulations. As the problem size grows, we encounter difficulties in solving these models, and thus we propose a Benders reformulation. We solve this formulation using a branch-and-cut algorithm. The separation, which is exact and polynomial, is done by inspection.

Computational Results

We use four different sized data sets to perform our computational experiments. The first one is a commonly used data set in the RSLP literature. We generated the other data sets based on the road network of Belgium. The nominal flow volumes are computed using the gravity model and the decision-dependency parameters are chosen using a similar way to that presented by [2].
We first compare the performances of the proposed solution methods. We observe that the Benders reformulation outperforms the other formulations. Then, we compare the station location decisions obtained by solving the deterministic, robust (without decision-dependency), and decision-dependent robust problems. We assess the importance of considering only uncertainty and uncertainty and decision-dependency simultaneously. In these experiments, we also examine the effect of different parameter settings on the results. Under all settings, we highlight the gain of incorporating uncertainty and decision-dependency into strategic-level decisions.

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Scheduling of search and rescue contacts for Galileo

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Keywords: global navigation satellite system, scheduling, integer linear programming

Motivations

In 2016 the European Union announced its global navigation satellite system (GNSS) called Galileo to be operational. Galileo reduces the geolocation distance error from four meters for the GPS to one meter. Standards of quality of service were imposed by the European Union on this GNSS in order to offer different services like the Search and Rescue geolocation assistance. Search and Rescue is coordinated by NATO and aims to set up emergency operations at an international level. To launch these operations, Galileo coverage rate must be of 99% for users around the globe and each user needs to be covered by two satellites.

Problem statement

For this problem, we have a fixed number of satellites which move according to a fixed orbit. We have a fixed number of ground antennas around the globe. For each slot of time over a finite time scale we want to allocate satellites to ground antennas and which must be "visible" by users, i. e., being within the elevation angle of the user. Each slot of time are called contact. Users have to be covered by two satellites during each contact as a Search and Rescue application. In the end, we want to maximize the coverage of users over time. We proved by reduction from a set covering problem that it is a NP-complete problem.

Realisations

The algorithm of reference is a greedy algorithm developed by the European Spatial Agency (ESA). For each slot of sixty seconds it decides an allocation between satellites, ground areas and antennas based on a set of priorities based on the European Union standards of service. I implemented their algorithm based on their scientific article in order to compare their approach with ours.

Our solution is based on a integer linear programming (ILP) algorithm. First, the orbits of Galileo satellites, the users and ground areas coordinates are parsed. Then, visibility windows between satellites and ground areas and between satellites and users are computed depending on an elevation angle. Last, a ILP algorithm is solved with the solver Cplex to allocate satellites to ground areas and antennas in order to maximize the number of users covered by two satellites during each slot of time (contact). Our ILP formulation is based around the concept of handovers. On handover is the time during one satellite or antenna disconnect and connect again to another one.

Tests, results and interpretations

The algorithm of reference and our ILP algorithm were implemented in C++ and solved in Cplex. All the needed data is actually public so we created several instances based on the real satellite's orbits and the antenna's coordinates. The users are modeled by dots equally distributed around the globe.

The mean cover rate of our solution is identical to the ESA algorithm one's. Besides, both stay stable over the instances. However, the model proposed leads to fewer handovers. Indeed the number of handovers is reduced by a factor of ten. For practical reasons, it is considered as a better solution by causing less wear and tear of the satellite's components.

Conclusion

To answer the problem of maximal user coverage by two satellites connected to ground antennas, we propose a ILP formulation based around the concept of a handover. Our ILP algorithm gives better scheduling solutions than the greedy algorithm proposed by ESA because they reduce the number of handovers by a factor of ten for the same user coverage.

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Lower bounds for the joint batching, routing and sequencing problem

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Keywords: warehouse management, order batching, column generation.

Introduction

Warehouses are nowadays the scene of complex logistics problems integrating different decision layers. The scene takes place in a tall and dim building, lights flickering with a buzzing noise. Pickers move across the warehouse, collecting items, fulfilling customer's orders. A digital voice for companionship.
To increase the efficiency of the operations, several orders might be batched, i.e., put together to be collected by a picker in one single route. Batching is possible as long as orders grouped together respect capacity constraints, namely they fit in a trolley. Since customer satisfaction is at the core of competitiveness in e-commerce, each order is required to be prepared and shipped before a strict deadline that usually corresponds to the departure of a truck from the warehouse to deliver orders. Pickers must therefore collect their batches in an appropriate sequence in such a way that all orders meet their deadlines. Planning the entire process is referred to as the Joint Order Batching, Picker Routing and Sequencing Problem with Deadlines (JOBPRSP-D).
In the present work, we consider optimal routing policies in rectangular warehouse with several blocks (or cross-aisles). Such optimal routes can be efficiently computed with dynamic programming following the work of Pansart et al. [1].

A bin-packing formulation

In the literature, relatively efficient methods have been designed for single problems such as the picker routing problem, however the resolution of integrated problems is receiving attention since significant gains can be achieved by taking into account

the interrelations of the planning problems. These problems are very challenging to solve, and practical instances tend to be of large size which complicates even more the resolution. Consequently, heuristic approaches have been favoured so far to solve these integrated problems.
The algorithms proposed so far to solve the JOBPRSP-D are all based on meta-heuristics like for example iterated local search [2]. In this work, we propose an approach to provide lower bounds for the JOBPRSP-D. The sequencing aspect of the JOBPRSP-D has been considered so far as a scheduling problem where the batches of each picker have to be scheduled in order to satisfy the orders' deadline. In this work, we show that the JOBPRSP-D can be formulated as a (multiple) bin-packing problem instead of a scheduling problem. This is possible since there are no release date for the orders. The main advantage of such a bin-packing formulation is to provide a tractable exponential linear programming formulation, that is strengthened by classical valid inequalities derived from the bin-packing problem.

A column generation heuristic

We propose a column generation heuristic able to provide valid lower and upper bounds on the optimal value of the JOBPRSP-D. From the bin-packing formulation, we show that the methodology proposed by Briant et al. [3], that is a column generation heuristic with performance guarantees for the Joint Order Batching and Picker Routing Problem (JOBPRP), can be extended to tackle the sequencing question. Moreover, a key cutting plane that was used for solving the pricing of [3] can be considerably strengthened by using timing considerations related to the sequencing aspect of the problem.
The proposed algorithm is evaluated on publicly available data-sets. It is able to optimally solve instances with up to 18 orders in few minutes. It is also able to prove optimality or to provide high-quality lower bounds on larger instances with 100 orders. To the best of our knowledge this is the first work that provides optimality guarantee on large size instances for the JOBPRSP-D, thus the results can be used to assert the quality of heuristics proposed for the same problem.

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Solving the integrated order picking and vehicle routing problem in a dynamic setting

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The ever increasing expectations of customers require companies to improve their operational performance. After the customer enters an order in the system, the ordered goods have to be picked in the warehouse and delivered to the customer's location. In the traditional order handling process, the order picking and order delivery processes are handled individually. The ordered items have a certain picking deadline, and the order picking operations are optimised based on this deadline. Afterwards, the delivery operations are scheduled to deliver the items to the customer. However, interactions between order picking and delivery exist, which are ignored in this sequential optimisation approach. Therefore, the use of more complex solution algorithms, taking the interactions between picking and delivery into account, may lead to better solutions.

Previous research already looked into the integration of order picking and delivery. The results indicate that solving the integrated problem leads to considerable efficiency improvements compared to handling both problems individually. In the existing studies, however, all orders were available at the start of the planning period. In practice, orders will arrive during the operations, requiring a solution algorithm capable of dealing with dynamic order arrivals. Solution approaches handling dynamic order arrivals do exist for the order picking and vehicle routing problems individually, but are not yet studied for the integrated problem.

We propose new metaheuristic algorithms to solve the integrated problem while accounting for dynamic order arrivals. Multiple solution algorithms were developed and tested, each solving the problem in its own specific manner. Based on these tests, benefits and drawbacks of the different algorithms can be studied, leading to better insights in the integrated problem and its preferred solution approach.

A column generation approach to solve the joint order batching and picker routing problem including picker congestion

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Introduction

Order picking is one of the most important processes in warehouse operations and deals with the preparation of different customer orders. The tasks associated with the order picking process are usually performed by human operators who push a trolley around the warehouse to collect the required products. At the operational level, the two main decisions taken by managers are the batching of orders and the routing of pickers. The order batching problem (OBP) consists in determining the set of orders assigned to each picker. The picker routing problem (PRP) is to define the minimal distance tour to collect all the products of a given set of orders. In an integrated approach, the joint order batching and picker routing problem (JOBPRP) considers both decisions jointly and can be solved to optimality with a branch-and-cut approach [1]. In the literature, a common assumption is the non-existence of congestion produced by pickers. In this work, we propose to include the effect of congestion as a delay in the nominal travel times.

Modeling and solving the JOBPRP including picker congestion

We consider a warehouse with several parallel aisles, each of them divided into several sub-aisles. To quantify the delay produced by congestion, the planning horizon is divided into homogeneous time intervals, and the number of pickers visiting each sub-aisle is computed. If more than one picker visits a sub-aisle during the same time interval, all these pickers incur a delay in their travel time. The delay function

increases with the number of pickers. To mathematically formulate the problem, we propose an extended formulation in which variables (or columns) represent possible picking routes. Each column is associated with information about the total time and level of congestion in each visited sub-aisle at each time period.
To solve the model, a heuristic column generation approach is proposed. First, the resolution of the linear relaxation of the extended formulation is performed using a column generation algorithm. In each iteration, for a given set of columns, the restricted master problem is solved, and then a set of negative reduced cost columns are added by solving the dedicated pricing sub-problem. Once the relaxation is solved (there are no more negative reduced cost columns to add), the integer problem is solved with the columns obtained in the previous step, in order to provide an upper bound. The value of the linear relaxation is a lower bound, and we can thus report performance guarantee.

Pricing columns through a labeling algorithm

One of the most important components of the algorithm is the production of negative reduced cost columns with a pricing algorithm. In the case of the JOBPRP with congestion, using a commercial solver for pricing is not relevant since the non-linearity of congestion is difficult to model, and optimal solutions can be obtained in reasonable time only for very small size instances. The pricing problem can be formulated as a dynamic program, and in this work, we developed a label correcting algorithm to solve it. The principle of this algorithm is to associate a label to each feasible partial picker route. Each label has a set of attributes that indicate the consumption of different resources in the partial route: the total time including delays imposed by congestion, the collected items and orders, the arcs used in the route, and the congestion charge in the visited sub-aisles. We consider a graph were nodes represent the picking locations where items have to be collected, and arcs represent a shortest path in the warehouse to travel between the corresponding locations. To each node are associated the labels that represent a partial picker route ending at the corresponding location. The algorithm iteratively extends labels associated to a node to its successor nodes. At the end of the algorithm, we keep all labels associated to the end depot with a negative reduced cost. It can be noticed here that, contrary to usual label correcting algorithms we do not use dominance rules to eliminate labels because of the congestion aspect of the problem.
To evaluate the entire solving process, several experiments on instances from the literature were performed, and the relevance of the obtained solutions is discussed.

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To do or not to do? Cost-sensitive causal classification with conditional average treatment effect estimates

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Keywords: Causal classification, Expected profit, Classification boundary

Conditional average treatment effect (CATE) models allow optimizing decision-making by predicting the effect of a treatment on an outcome of interest for individual instances. These predictions allow selecting instances to treat in order to optimize the overall efficiency and net treatment effect.
In this article, we extend upon the expected value framework and introduce a cost-sensitive causal classification boundary for selecting instances to treat based on predictions of individual treatment effects and for the case of a binary outcome. The boundary is a linear function of the estimated conditional average treatment effect, the positive outcome probability and the cost and benefit parameters of the problem setting. It allows causally classifying instances in the positive and negative treatment class in order to maximize the expected causal profit, which is introduced as the objective at hand in cost-sensitive causal classification.
We present the expected causal profit ranker which ranks instances for maximizing the expected causal profit at each possible threshold that results from a constraint on the number of positive treatments and which differs from the conventional ranking approach based on the individual treatment effect. The proposed ranking approach is experimentally evaluated on synthetic and marketing campaign data sets. The results indicate that the presented ranking method outperforms the cost-insensitive ranking approach.

The impact of non-ergodicity on decision-making

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Keywords: Decision Making, Ergodicty Econmics, Time Series Analysis

Expected values are a frequently used first-order approach to model a system subject to stochasticity, such as human decision-making and forecasting. But do expected values help us to make correct decisions or forecasts? The concept at the core of this question is the one of (non) ergodicity. A system's underlying dynamic is ergodic when its expected value and time average can be used interchangeably [O. Peters, 2019]. In other words, when we make n observations at one time step or track one element over n time steps, we should come to identical predictions and conclusions about our system. When the ergodic hypothesis fails, a system drifts away from its expected value which becomes an increasingly poor indicator as time goes on. Consequently, the time average becomes a more appropriate indicator. Rarely do people ask the question of whether a system of interest satisfies ergodicity, but it has far-reaching effects.

Decision theory provides an example of this. In decision theory, the most widely adopted theories, utility theory [R.Keeney & H. Raiffa, 1993] and prospect theory [A. Tversky & D. Kahneman, 1992], have concluded that humans are irrational albeit consistent decision-makers. Both paradigms come to this conclusion by observing that humans are poor expected value optimisers bogged down by personal bias and heuristics. Ergodicty Economics reconceptualises these findings by asking the ergodic question, What if the decisions of economic actors are based on non-ergodic processes rather than ergodic ones?.

Inspired by earlier work by Meder et al. (2019) we set up three stated choice experiments in which we submit human decision-makers to both ergodic (additive) and non-ergodic dynamics (multiplicative or additive-ruin). In these dynamics, the individuals are tasked with selecting their preferred bet or redistribution amount. In the first experiment, we find evidence of intuitive human decision-makers optimising the time average rather than the expected outcome of their choices. Secondly, we set up an experiment incorporating catastrophic failures with different likelihoods while keeping the expected outcomes for all respondents equal. We observe a strong relationship between human decision-making and proximity to ruin (catastrophic failure) that is not extant in ensemble average frameworks. These findings underline

the significance of time averages in human decision-making over ensemble averages.

Another type of rational behaviour predicted by ergodicity economics, as opposed to expected value optimising models, is redistribution within a multiplicative dynamic. Erogodicity economics tells us that time growth rates within this dynamic are a consequence of both the expected value and the variance of a dynamic $\left(g_t = \mu - \frac{1}{2}\sigma^2\right)$ [O. Peters (2019)]. By redistributing, humans can trade some of the expected outcomes for a reduction in variance. While the theory behind redistribution within ergodicity economics is well described, relatively little is known about whether humans have internalised this trade-off and act accordingly. Within a third experiment, we tested this hypothesis and found that respondents tend to redistribute through which they sacrifice the expected outcome for the time average.

In summary, ergodicity is a critical and often overlooked concept when modelling stochastic systems. One field that can benefit in particular from the insight originating from the study of non-ergodic dynamics is decision theory. Our experiments show that humans optimize the time average rather than the expected outcome, which casts a different light on the stigma attached to humans and their (ir)rationality. Nevertheless, decision-making is not the only field for which the ergodic question is relevant, as it turns out most, if not all, of the systems we observe, are non-ergodic.

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Enhancing credit risk data quality using machine learning techniques

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Keywords: Data Quality, Credit risk, Model ensembles

Problem statement Data plays a crucial role in decision-making for modern businesses. The reliability of these decisions depends on the quality of the data used. Poor quality data can lead to unreliable choices, known as the "Garbage in - garbage out" problem. This is especially important for financial data due to regulatory requirements for improved data quality.

To ensure stability in the financial system and comply with regulatory requirements, banks need to assess the level of risk associated with their assets. Basel regulations mandate that banks hold a certain amount of capital based on the level of risk in their portfolios expressed in the form of risk-weighted assets (RWAs) [1]. The quality of a bank's risk management is directly impacted by the quality of the asset data used to calculate RWAs. However, manual data quality assessment can be impractical for large volumes of data, making it difficult to detect quality issues in a timely manner. To address this challenge, unsupervised machine learning (ML) models can automatically identify data quality issues, enabling efficient and effective data quality assurance.

The goal of this study is to investigate how ML models can be used to discover data quality problems in credit risk data using a human-in-the-loop approach. By performing

this research, we bridge the data quality and credit risk domains as well as bring together AI and human intelligence. First, we apply an ensemble of the isolation forest (iForest) and autoencoder models in order to detect data quality issues. Next, we obtain true labels for top-detected data quality issues from data quality domain experts and evaluate the quality of the ensemble. Finally, we utilize this feedback in order to calibrate outlier scores for each model.

Methodology In order to investigate the research question, we employ the credit risk data for loans of a large European bank. The data comes from a data warehouse that consolidates the data coming from local source systems. The scope of the data is narrowed down to the loan for large business customers with large RWA values in order to discover data quality issues that are specific for high-risk assets. To ensure the discovery of data quality issues in the feature that affects RWA calculation, we perform feature selection and narrow the feature set to the following features: Outstanding amount, Provisions, Exporure-at-Default (EAD), Loss Given Default (LGD), Probability of Default (PD), Maximal Limit, Net Sales of a Legal Ultimate Parent, and the RWA itself. To take into account changes across time, we utilize ratios with respect to a previous month rather than static values of a particular month for these features.
As the data quality issues are unexpected and unknown, there are no true labels available in the data. Hence, we deal with an unsupervised learning problem and employ unsupervised anomaly detection models. In particular, we employ iForest and autoencoder models that have been proved to perform well in the literature [2]. As the scales of the outlier scores returned by these models are different, we linearly transform the scores into the range [0,1]. In order to get the best of both models, we aggregate the outputs of two models in an ensemble and return the final prediction by averaging their outlier probabilities. According to the initial feedback from a domain expert, 10 out of the top-20 detected cases appear to be true potential data quality issues, resulting in a precision at top 20 cases of 50%. Moreover, it is worth noting that two of these cases are directly linked to the RWA calculation, which underscores their importance and significance in the context of data quality.
Our future research is focused on improving the calibration of outlier scores into outlier probabilities by, e.g., using mixture modeling of outlier scores and learning its parameters using a semi-supervised Expectation-Maximization framework proposed by Gao and Tan (2006) [3].

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Formulations and branch and cut algorithms for the heterogeneous fleet vehicle routing problem with deadlines

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We study a variant of the heterogeneous fleet vehicle routing problem that integrates customers' deadlines and allows for the violation of deadlines at a tardiness penalty cost. The objective is to determine the fleet composition and vehicle service routes to minimize the total cost composed of fixed cost, routing cost and tardiness cost, such that each customer is visited exactly once and each vehicle route respects the limits on the daily working hours. To tackle this problem, we present three compact formulations for the problem, namely Miller-Tucker-Zemlin formulation (MTZF), single-commodity flow formulation (SCFF) and two-commodity flow formulation (TCFF), and compare their linear programming (LP) relaxations. To strengthen the LP relaxations of these formulations, we propose two new families of valid inequalities, along with the well-known generalized subtour elimination constraints and use these within branch-and-cut solution schemes. Computational experiments are conducted on a set of new instances generated using the Solomon instances. The results show that SCFF and TCFF outperform MTZF, and that incorporating valid inequalities enhances computational performance of the formulations. Finally, we examine the effects of relocating the depot and varying customer weights.

Air cargo ground operations optimization: A service vehicles coordination problem

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Keywords: Vehicle routing problem, Synchronization, Precedence

Air transportation plays a significant role in e-commerce, whose volume of activity increases year after year and has known a real explosion in 2020 when the covid-19 crisis emerged. However, the air cargo field is mainly driven by historical "best" practices without strong coordination among the stakeholders providing the different ground service equipment. As a consequence, many challenges need to be overcome, especially at the ground operations level. Those logistical activities which are performed between the time a cargo plane lands and the time it takes off again indeed offer big rooms for improvements. In this regard, ground service equipment coordination has been identified as a common bottleneck in the operations flow and is the cause of most delays. Beyond the impact on customer satisfaction, flight delays are a financial burden for the concerned airlines and may cause additional environmental damage by increasing fuel consumption and gas emissions. It is therefore crucial to find ways to optimize the air cargo supply chain.

The present work seeks to optimize air cargo ground operations by coordinating the different ground service equipment, the idea being to develop a decision system that optimizes the journey of the different service vehicles considering the precedence and synchronization constraints that bind some ground operations or vehicles together. As each ground operation requires a fleet of vehicles to serve different clients within a defined time interval, it seems reasonable to tackle the problem as a set of vehicle routing problems with time windows, each VRPTW referring to a given ground operation. Those VRPTWs should consider capacitated and heterogeneous vehicles, deal with forbidden pairings and split deliveries, and allow both multi-trips and fleet sharing. Their complexity is further reinforced by goods transfer between vehicles, which leads to dependency between some vehicles and the use of multiple recursive processes. Precedence constraints between operations also make the problem more complex as they induce dependency between some operations. Scheduling decisions made for an operation or a vehicle therefore affect the scheduling decisions for other operations or vehicles respectively. In addition, many additional problem characteristics should be considered. These include among others the fact that some vehicles

can perform different operations and must follow a specific services sequence, that some operations consist in carrying vehicles required by other operations, that some vehicles can be replenished while others cannot, that some operations entail a trip, that the number of some vehicle types is restricted in certain places, or that some operations experience a random extra operating time.

Due to the complexity induced by the numerous problem features considered, it is highly likely that exact methods would not succeed in finding an optimal solution or, at least, finding one within a time frame which is small enough to be viable in the dynamic airport environment. Indeed, since input data evolves over time and is subject to disruptions, it seems preferable to build an algorithm that is able to compute and recompute good solutions very quickly. In this regard, note that even if each sub-problem takes the form of a VRPTW, we do not try to minimize the total distance travelled or the number of vehicles in use as is often the case. Instead, we are looking for solutions that minimize the total responsiveness, that is solutions which complete operations as soon as possible, within the time window, such that both the aircraft and the different service vehicles can operate again. Such an objective function allows to increase the time left before the theoretical aircraft departures, which can be seen as a buffer that could absorb any disruptions and therefore subsequently help to minimize total aircraft delay on the time horizon considered.

Literature remains relatively sparse on that topic, with most authors focusing only on the passenger side, considering only a specific ground operation (meaning that they do not approach the prioritization problem induced by precedence constraints between operations nor the synchronization problem arising from goods transfer between vehicles), or dealing only with some of the numerous features of the problem. The originality of this work lies therefore in the fact that we are approaching the complete picture of air cargo ground operations coordination problem. In addition, the algorithm which is currently developed is designed in a way that it would be possible to use it in any application presenting the same problem structure, making this work relevant not only to the air cargo industry. The approach is thus intended to be general and applicable to different problems requiring services coordination, air cargo ground operations being only a use case to illustrate the research.

This work is part of a doctoral thesis in progress and constitutes the first step of a long-term project. So far, the first objective of this work, which is to identify and classify a range of issues related to services synchronization, is already achieved. The second objective, which is to propose a basic heuristic that is able to address the complete problem, is under development. We hope to be able to present some preliminary results by the time of the conference.

The internal warehouse replenishment problem: a heuristic approach based on the orienteering problem

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Keywords: Inventory; Warehousing; Forward reserve; Replenishment; Orienteering problem

Storing inventory in both a reserve and forward area is a way to improve the efficiency of a B2C warehouse. The smaller size of the forward area allows order picking distances to be reduced, but internal replenishments from the reserve to the forward area are necessary to keep the warehouse up and running. In this paper, we study how to replenish the forward area in order to minimize the number of stockouts during order picking whilst integrating practical issues, such as limited work force and replenishment time. We introduce the internal warehouse replenishment problem (IWRP) that determines which products to replenish, in which quantity and by which replenisher, and this for an out-of-rack forward reserve system where replenishing and picking is performed sequentially, in successive cycles over the day. In our model, a multi-replenisher situation is assumed, where each replenisher is allowed to perform several replenishment tours in a fixed time. Due to the cart's capacity, however, only a limited number of bins can be replenished per tour, and with both travel and handling time taken into account, the total replenishment effort assigned to a replenisher is not allowed to exceed the available time. We present the mathematical model for the multi-cycle IWRP, but due to its complexity we solve it iteratively, cycle by cycle, denoted as the single-cycle IWRP. For small instances, the model is solved by a mixed integer linear program solver. For the larger instances, a heuristic approach is proposed based on the orienteering problem (OP). We align the score assignment of the OP with the IWRP-objective, and integrate the obtained scores in a variable neighborhood search algorithm. Experiments demonstrate a superior performance of the proposed heuristic opposed to the exact solver and our greedy benchmark heuristic. In contrast to the latter, the IWRP heuristic improves the number of stockouts by 15,16% for small instances, and 24,26% for larger instances.

Choosing is losing... or winning? – The influence of human autonomy on job assignments in warehousing

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Warehouses play a prominent role in a company's supply chain and contribute to its failure or success. Many activities are performed within a warehouse, but it has been shown that order picking (OP) is by far the costliest. Order picking is defined as the process of retrieving goods from their storage locations in a warehouse. In consequence of the large share of OP in total warehousing costs, warehouse managers pursue attaining high efficiency levels regarding their OP system. Several planning problems can be invoked to respond to this aspiration, for instance batching, routing, or job assignment [1]. However, in many of today's warehouses, a central planning system governs these planning problems and sets out directives for human workers. This erodes the perceived autonomy of order pickers, although autonomy is one of the three basic psychological needs and found to affect worker well-being. This study presents the development, testing, and post-hoc evaluation of an autonomy-increasing experiment in a real-world warehouse. We show that granting autonomy to order pickers has a beneficial impact on individual well-being as well as organisational outcomes.

One planning problem which contributes to efficient warehouse operations, is the job assignment planning problem. This planning problems coordinates the allocation of orders/batches/tasks (henceforward: orders) to pickers, as well as the sequence in which these should be picked. In many of today's warehouses, those assignments are completely random, apart from possible due dates (or priority) considerations. This leads to the underutilisation of pickers' skills, as picker-order misfits may occur. For example, a relatively short order picker may be assigned to top-shelf picks, or a picker with fear of heights is required to pick boxes at great height during his pick tour. Such mismatches can be avoided by repeatedly assigning pickers to specific orders, which are in line with their respective skills. However, previous research has highlighted the aversion of pickers from being assigned to products with the very

same characteristics over and over again [2]. In addition, this form of repetition may physically overstrain pickers, and lead to boredom as a result of monotony. The question arises whether it is possible to configure a system in which picker skills can be exploited, without compromising pickers' physical and mental well-being.

The aim of this study is to configure such a system and assess its impact. In particular, we developed an order assignment mechanism (OAM) in which order pickers get the opportunity to choose their next order from an order set that is presented to them at the depot. This novel OAM was tested during a three-week lasting experimental period in a real-world warehouse, thereby boosting the external validity of this study. We adopted a within-subjects study design, since one of our experimental treatments was the current OAM of the respective warehouse. To evaluate the impact of this newly-developed working system, a holistic evaluation approach was adopted, as psychosocial-, physical-, and performance-related outcome measurements were collected. Psychosocial variables include perceived autonomy, task variety, job satisfaction, and motivation, whereas physical outcomes pertain to heart rate monitoring. Last, performance is conceptualised by number of order lines, and number of pallets picked. In total 18 order pickers voluntarily participated in our study. Results indicate a significant increase in psychosocial worker well-being, as well as positive, albeit non-significant, indications of enhancements in physical well-being when working in a system with more decision autonomy for workers. Productivity measurements remained unaffected. To delve deeper into the observed results, an additional layer of information was added via post-experimental semi-structured interviews. Those interviews revealed a very high user-experience and a keen desire to adopt the newly-proposed OAM. Arguments to underpin this conviction include the reduction of monotony, the provision of accurate information and thereby concrete perspectives, and the possibility to increase picker-order fit.

This study shows how high efficiency levels can coincide with increased worker involvement. Using a holistic evaluation approach, we show the beneficial impacts of an autonomy-increasing intervention in a real-world warehouse. The insights derived from this study can be translated to other warehouse planning problems and give rise to several subproblems which ought to be encountered with an OR perspective

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A data-driven analysis of route deviations in an order picking process

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Keywords: Maverick picking, Data-driven analysis, Warehousing

Order picking is recognized as the most expensive warehouse operation, especially for picker-to-parts systems in which order pickers travel through the warehouse to collect products following a pre-determined route. Researchers developed numerous optimal and heuristic routing policies. However, those routing policies often consider a single order picker in isolation or assume that multiple pickers' routes are performed independently. In reality, numerous pickers travel through the warehouse simultaneously, and their routes can interfere. For example, picker blocking occurs when multiple order pickers need to access the same storage location or when an order picker cannot pass another order picker in the same pick aisle due to a lack of space. Additionally, people are often reluctant to use algorithmic decisions either consciously or unconsciously and, therefore, might deviate from the proposed plan. These phenomena add uncertainty to the picker routing problem and can lead to higher picking times than expected.

Using human pickers to fulfill order picking activities makes the process more flexible. For example, when experiencing a blocked path, an order picker can independently decide to wait or deviate from its planned route. Maverick picking considers how an order picker deviates from its planned workflow. Although maverick picking is deemed important, only two papers have been published about the subject. Additionally, recent research has shown that insufficiently comprehending and incorporating human behavior in order picking models could lead to dissatisfaction, chronic stress, employee turnover, and burn-outs for order pickers when implemented in practice. In the first paper about maverick picking, the authors use a qualitative approach by conducting surveys to find the types, causes, and consequences of

maverick picking. The authors conclude that, although positive effects are possible, the consequences of maverick picking on order picking efficiency are mainly negative [2]. The second paper compares optimal and heuristic routing strategies considering route deviations. To do this, the authors use agent-based simulation to analyze the effects of route deviations on picking time under different routing methods. A range of artificially selected probabilities determines whether a route deviation occurs. They conclude that it is essential to consider route deviations when determining the preferred routing strategy [1]. From both papers, it can be concluded that the effects of maverick picking are significant and, thus, should not be ignored. However, a quantitative justification for their conclusions is still lacking.

To summarize, through qualitative research and simulation experiments on artificial data, existing literature has indicated the detrimental effect maverick picking may have on operational performance. Yet, the literature lacks (the tools for) a quantitative assessment of how prevalent this aspect truly is in practice and a quantitative analysis of the underlying causes. At the same time, data on individual order pickers is readily available in many warehouses. That is why we will improve warehousing research using historical data analysis to quantify the prevalence of maverick picking and to find patterns that cause them. Firstly, this will allow analyzing the real-life impact of maverick picking. Secondly, improved order picking planning models considering these new insights will be proposed. The improvement will lead to outputs from order picking planning models that more closely resemble reality and increase the likelihood of warehouse managers actually using scientific research on warehousing. More specifically, as the effects of maverick picking are expected to be mainly negative, the overall warehouse performance will no longer be overestimated. This will result in achievable expectations from warehouse managers and, therefore, higher employee well-being and lower burn-out rates among order pickers.

As order picker deviations may manifest in different ways, the aim is to identify both deviations from the planned pick order of items (e.g., locations in a pick aisle were skipped because the aisle was congested) and deviations from the expected times at which picks are performed (e.g., delays due to picker blocking or pickers taking alternative travel paths). First insights based on an extensive real-life data set will be presented.

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Extracting key insights from corporate earnings press releases and earnings call transcripts

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This ongoing project aims to evaluate the impact of corporate earnings press releases and earnings call transcripts on financial analysts' decision-making processes. Specifically, we focus on identifying novel and relevant information contained in these documents and developing a methodology to automate content evaluation.
We analyze a large-scale dataset of earnings press releases and earnings call transcripts from US companies across various industries, covering the period 2012-2022 on a quarterly basis. We use natural language processing (NLP) techniques to identify key topics and trends in the documents, distinguishing those that differentiate documents and extract relevant passages for analysts.
Our study investigates the presence of novel and relevant information in earnings press releases and assesses the impact of this information on market reaction. We analyze the impact of new information on liquidity metrics as a proxy for market reaction.
This research contributes to the growing body of research on the role of information disclosure in financial markets and highlights the importance of developing innovative methods to extract and analyze relevant information from long text documents. By improving the efficiency and accuracy of content evaluation, our methodology has the potential to enhance analysts' decision-making processes and improve market efficiency.

Tree based Gibbs sampling for hierarchical topic model

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Abstract

In Natural Language Processing, several methods for extracting themes (or topics) from a corpus have been proposed. In particular, hierarchical topic models, such as nHDP, enable the extraction of topics and sub-topics organised in a tree-like hierarchy. Additionally, these models dynamically determine the appropriate number of topics and sub-topics during training. These topic models have been applied to various tasks, including document summarization, environment scanning , understanding employee and customer satisfaction among others.
Nevertheless, the latest topic model (nHDP) was trained using Stochastic Variational Inference (SVI), an approximate sampling method sensitive to hyper-parameter choices. The approximation provided by SVI is generally affected by the model or dataset complexity, and quantifying the approximation error can be difficult. Nonetheless, the initial choice of using SVI was motivated by the fact that the usual Gibbs sampling method is inappropriately slow to train complex model such as nHDP.
In our work, we propose a new implementation of Gibbs sampling which offers several advantages over SVI, such as exact sampling and improved convergence properties. Moreover, Gibbs sampling performs better on smaller dataset which could lead to more precises extraction of small sub-topics. Through data structure engineering, we managed to achieve similar speed to SVI, removing its biggest advantage.
In particular, we propose a new data structure we call Infinite Dirichlet Trees (IDTs). IDTs are used to model topics and their hierarchy. Each node in an IDT represents a topic and contains information about the words assigned to that topic. The nodes also represent the hierarchical distribution of topics, with words being assigned to a final topic and all its ancestors. By using IDTs, we can optimize all the distributions jointly and use the trees directly as output to view the topic hierarchy for the corpus and each document.

A review and experimental evaluation of the state-of-the-art in text classification

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Keywords: Text Classification, Benchmark, Machine learning

In the existing literature, there is a shortage of impartial and extensive benchmark studies comparing models of different complexity for several different text classification tasks. More often, studies provide a benchmark of techniques with similar complexity or they focus on only one specific text classification task. To address this gap in the literature, we compare different methods of varying complexity on five different text classification tasks: fake news detection, topic detection, emotion detection, polarity detection, and sarcasm detection. The methods that we compare consist of simple machine learning methods, e.g. logistic regression (LR) and support vector machines (SVMs), ensemble methods, e.g. XGBoost (XGB) and random

forest (RF), neural networks, e.g. bidirectional LSTM (BiLSTM) and convolutional neural network (CNN), and transformer-based methods, e.g. RoBERTa. We train models 15 different datasets divided over the various text classification tasks and perform statistical tests to come to generalizable conclusions.

Our results show that BiLSTMs outperform all other methods over all different text classification tasks and datasets. However, this method did not significantly differ from LR combined with Term Frequency Inverse Document Frequency(TF-IDF) as preprocessing method and RoBERTa. When zooming into the different text classification tasks, we find that BiLSTMs perform best for every task except topic detection. For this classification task, LR TF-IDF is the best-performing method. This finding is not surprising, as this means that for topic detection, no real understanding of the context of a word is necessary. It is enough to focus on the important words to identify the general topic. For fake news detection, XGB combined with FastText word embeddings is the second-best ranked method, though this method did not perform as well for the other classification tasks. Furthermore, we see that RoBERTa is the second-best performing technique for both emotion and polarity detection. Finally, we find that RoBERTa performs significantly worse than BiLSTM for sarcasm detection being the worst-performing method for this classification task. For two out of three datasets we find that RoBERTa always predicts a sentence to be non-sarcastic. This might be due to the high class imbalance of one of the two datasets and the small number of documents in both. Furthermore, it can also be due to the fact that RoBERTa is a pretrained language model, pretrained on a mostly non-sarcastic text corpus.

Our research has demonstrated generalizability across various tasks and datasets, although statistical tests did not yield significant differences in some cases. In light of this, we recommend expanding upon the current benchmark study to gain deeper insights. Furthermore, it is challenging to ascertain whether differences in performance can be attributed solely to the differences in text classification tasks or dataset specifications, or if they are a result of a combination of these factors. Additional experiments are required to clarify the exact relationships between these factors.

Rejection-proof kidney exchange mechanisms

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Keywords: Bi-level optimization, Game Theory, Kidney Exchange

Introduction

For patients suffering from end-stage renal disease, a kidney transplant from a living donor is the preferred treatment option. A donor must be medically compatible with the recipient, which means some recipients can not receive a transplant, even though they have a donor willing to undergo a transplant for them. We refer to such a combination of recipient and donor as a *pair*. Kidney exchange programs (KEPs), aim to match the recipients from a pair with compatible donors from other pairs. Donors in a pair only donate if their paired recipient receives a transplant in return, leading to cycles of transplants. Kidney exchange programs may also include so-called non-directed donors (NDDs). These donors are not associated with a recipient, and are willing to donate to any recipient in the program, leading to donation chains. Typically, kidney exchanges have a policy limiting the maximum length of cycles and chains.
The outcomes of kidney exchanges generally improve with the increase of the size of the pool of pairs and the number of NDDs, as the number of potentially successful donors increases for all patients. Cooperation between hospitals or national kidney exchanges (here referred to as agents), can thus increase the total number of transplants. While multi-agent kidney exchanges (mKEP) aim to increase the total number of transplants, the competing goals of agents raises issues. Indeed, single agents are primarily interested in transplanting their patients, rather than achieving the overall social optimum. Thus, when designing mechanisms for mKEPs, we must consider the strategic behavior of agents that is aimed at increasing transplants for their own patients.
In this work, we consider the following strategic behavior. The collaboration has full information on the pools of all agents, and first proposes a solution (a set of cycles and chains). Next, agents may reject some or all of these proposed exchanges, and instead use their now unmatched patients and donors to perform other internal exchanges. Our goal is to obtain what we call *rejection-proof* solutions, solutions so that no agent has incentive to reject any exchanges.

Rejection-proof mechanisms

We consider three different mechanisms which guarantee rejection-proof solutions.

- MaxRP-KEP: A mechanism which identifies the rejection-proof solution with maximum social value.
- MaxInternal: A mechanism which identifies a solution with maximum transplants from internal exchanges, with social value as tie-breaker.
- Reject-and-Rebuild: A mechanism which identifies a rejection-proof solution through an iterative process, and adds additional shared exchanges if possible.

Results

We show that finding the rejection-proof solution with maximum social value is a Σ_2^{P}-hard problem. This implies no compact integer programming formulation exists. Indeed, a natural formulation of the problem is a bi-level integer program. The upper level of this program is a kidney exchange program, with the additional constraint that each agents must receive a value equal to what they can achieve in the lower problem. We propose a single-level reformulation with an exponential number of constraints, which we solve through a cut generation algorithm. This procedure allows us to solve medium size instances (100 patients/donors), with variation depending on graph density and number of agents.
Through experiments on realistic kidney exchange graphs, we show that rejection-proofness comes at a limited cost. Optimal rejection-proof solutions are on average within 1% of the overall optimal solution. In fact, as kidney exchange problems often have many optimal solutions, there often exists an overall optimal solution that is also rejection-proof. The two heuristic mechanisms (MaxInternal and Reject-and-Rebuild) lead to larger losses of transplants (up to 15% and 7% respectively).
A preprint version of this work can be found on arXiv [1].

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Fair integer programming under dichotomous preferences

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Keywords: Integer programming, fairness, column generation

We propose a unified framework to control the selection probabilities of optimal, or near-optimal, solutions for integer linear programming formulations in which agents have *dichotomous* preferences, i.e., they only care about whether or not they are selected in the final solution. For a general class of integer linear programs, we propose several general-purpose algorithms to fairly select optimal, or near-optimal, solutions, such as maximizing the Nash product or the minimum selection probability, or using a random ordering of the agents for symmetry breaking (Random Serial Dictatorship). As such, we embed the "black-box" procedure of solving an integer program into a framework that is explainable from start to finish. Moreover, we study the axiomatic properties of the proposed methods by embedding our framework into the rich literature of cooperative bargaining and probabilistic social choice. Lastly, we evaluate the proposed methods on two specific applications, namely kidney exchange and minimizing the weighted number of tardy jobs on a single machine. We find that while the methods maximizing the Nash product or the minimum selection probability outperform the other methods on the evaluated welfare criteria, methods such as Random Serial Dictatorship perform reasonably well in computation times that are similar to those of finding a single optimal solution.

Dynamic pricing and dispatching in ride-sharing networks: A deep reinforcement learning approach

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Keywords: Ride-sharing platforms; Deep reinforcement learning; Markov decision process.

This work considers the problem of a ride-sharing platform that connects supply and demand in a network of locations over a finite horizon. The platform manages the network by making pricing and dispatching decisions. The goal of this research is to understand (i) how pricing and dispatching decisions can interact with each other to generate additional value, and (ii) to what extent the customer and driver behaviors influence these two decisions.
To address these questions, we propose an original model formulated as a discrete-time Markov decision process. In this model, the demand is composed of impatient customers who are heterogeneous in their willingness to pay. The driver supply can decide where to reposition according to the platform's prices in the different locations. The platform aims to find a joint pricing-dispatching policy that maximizes revenues while minimizing repositioning and abandonment costs.
Due to the "curse of dimensionality", the model is not solved with conventional dynamic programming methods. Instead, we use a deep reinforcement learning (DRL) framework to find a near-optimal policy. Specifically, we develop an algorithm that blends mathematical programming with DRL, proceeding in three steps. First, the algorithm finds a heuristic policy by solving multiple mathematical programs based on a deterministic relaxation of the model. Second, the algorithm trains a DRL agent to replicate the heuristic policy. Third, the algorithm accounts for stochastic components of the environment by using the Proximal Policy Optimization algorithm.
In a numerical study, we demonstrate the efficiency of our algorithm in comparison with other DRL algorithms, both in terms of final performance and computational effort. We then explore several managerial insights by applying our model to a case study in New York City. Namely, we study the consequences of optimizing only one of the two decisions (dispatching vs. pricing only) in comparison with optimizing the two decisions jointly. We then examine the implications of the customer and driver behavior on the algorithm's policy.

Deep reinforcement learning for combinatorial problems: A new approach for the 3DBPP container loading problem in logistics

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Keywords: Packing, Machine Learning, Operations Research

We will consider the case of the 3D Bin Packing Problem (3DBPP). It is classically formulated as follows: we have a set of containers where we need to store a set of cuboid boxes. Our objective is to place all the boxes in a minimum number of containers while avoiding exceeding the maximum capacity of each container and satisfying constraints of non-overlap between the different objects. This problem is NP-hard. Efficient heuristics are available for the 2DBPP, but the third dimension adds a significant level of complexity, at the combinatorial level itself, also with the addition of constraints that result from this third dimension in applications (management of fragility, stability, nature of the supports, weight distribution...).

While a traditional approach to tackling such problems is to resort to classical Operations Research techniques, some authors start considering techniques from other research streams, namely Artificial Intelligence (AI) and Machine Learning (ML). They have adapted and tested Reinforcement Learning (RL). In these approaches, an "agent" tests a possible sequence of actions and, in return, receives "rewards" from the "environment". By repeating sequences, the agent learns to recognize the most beneficial actions automatically. For complex problems, such as the one under consideration here, ML can be integrated into the framework. The approach is then renamed Deep Reinforcement Learning (DRL).

There is still much room for improvement. What can be observed from the literature on RL for the 3DBPP, is that a relatively small set of constraints has been considered so far. For example, besides the stability and orientation constraints that have already been incorporated in a few papers, many so-called "safety" and "logistic" constraints could be taken into consideration. We have also noticed that much of the literature on this topic is mostly focused on the single-bin configuration rather than the multi-bin setting.

Therefore, with this research, we plan on dealing with the 3 challenges outlined hereabove: the complexity of the problem which makes classical methods for the 3DBPP not efficient, the too-small number of constraints that have been addressed in recent literature on the subject, as well as the multi-bin setting which has been ignored up to now. To achieve this goal, we will build on an existing Deep Reinforcement Learning model for the 3DBPP we found in the literature, and determine a set of realistic constraints that could be added to this model while considering the multi-bin setting. This could also allow us to evaluate and compare the effectiveness of RL-based methods against well-known heuristics when a relevant set of constraints is considered.

Thus far, we have conducted a literature review and coded a first implementation of the model in Python. We hope that by the time of the conference, we will be able to present some results for a simple instance of the problem to add more constraints in the future.

A deep reinforcement learning proactive-reactive framework for real-time robotic mobile fulfillment systems

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Keywords: Optimization, Scheduling and Routing, Logistics

The e-commerce sector is undergoing a rapid transition towards more automation [1]. The increased complexity of the warehouse operations requires control systems that can efficiently and effectively manage this complexity. Especially in the case of real-time scheduling, efficiently dealing with uncertainty is crucial to ensure a good performance. Uncertainty is an inevitable aspect of real-world scheduling problems and leads to scheduling disruptions. A typical cause of disruptions is the variability in the processing time of picking tasks [2]. To manage these uncertainties, two main approaches are used: proactive and reactive scheduling approaches. Firstly, proactive scheduling involves making decisions ahead of time based on predicted system behavior. This allows the scheduler to allocate resources and prioritize tasks in a way that maximizes system performance and meets performance goals. The goal of proactive scheduling is to optimize the system behavior in a way that is robust to uncertainty. Secondly, reactive scheduling involves responding to changes in the system as they occur. In a reactive scheduling system, tasks are executed in response to events or changes in system behavior, rather than being scheduled ahead of time. The goal of reactive scheduling is to quickly respond to changes in the system to avoid deterioration of performance. While both approaches have their strengths and weaknesses, the choice between them depends on the specific requirements of the system. However, it is also possible to combine both methods to benefit from their advantages. We call this approach proactive-reactive scheduling, where the planning component generates a schedule proactively, and the reactive component responds to disruptions during execution by altering the schedule if necessary. The study of Ghaleb et al. [3] suggests that at some point during the execution of the schedule it is better to completely reschedule again instead of trying to repair the original schedule by making alterations to it. Hence, it is important to find a good balance between completely rescheduling, which is computationally expensive, and altering the original schedule to deal with uncertainties during execution.

To address the challenge of real-time scheduling in a robotic mobile fulfillment system (RMFS), we propose a proactive-reactive scheduling framework for coordinating the

mobile robots and human pickers. The framework uses a proactive genetic algorithm to generate an initial schedule. During execution of the schedule a reactive deep reinforcement learning (DRL) agent reacts to change in the environment. Based on the point in time of rescheduling by the reactive agent, a distinction can be made between periodic rescheduling and event-based rescheduling [4, 5]. In this study, rescheduling decisions occur event-based. The reactive DRL agent interacts with the environment and observes the changes, it is able to learn through trial-and-error from these interactions and construct a policy (π) by mapping situations to actions. The actions that the DRL can make are: exchange orders over workstations, insert orders in the queue, trigger the proactive scheduler to reschedule, or take no action. Taking no action is included to allow the system to simply follow the original schedule if the deviations have not accumulated too much. The objective of the proposed scheduling approach is to minimize the operational and capital costs related to the operation of the workstations and mobile robots in the warehouse environment. The proposed frameworks are extensively tested on a wide range of different instances varying in both the number of picking orders that have to be scheduled, various warehouse layouts, and a varying number of available resources (e.g. mobile robots, workstations, inventory racks, etc.).

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Integrated decision-making for medium-term home health care planning

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Keywords: Home health care, integrated decision-making, medium-term planning

Home health care (HHC) is essential to the health care industry and may be defined as care workers visiting patients following predefined schedules in order to provide medical services in their homes. Maintaining a sustainable and effective health care system is a significant challenge due to two trends: limited resources (e.g., budget restrictions and staff shortages) and a rise in demand (e.g., population ageing and pandemic outbreaks). In response to these trends and increasing competitive pressures, HHC providers must discover new ways to decrease costs and enhance productivity by optimizing the use of resources. Efficiently organizing HHC services requires making a wide range of complex decisions on multiple levels, ranging from day-to-day operational decisions (e.g., constructing routes and visit schedules) to tactical and strategic decisions impacting a longer time horizon (e.g., rostering care workers and determining staffing levels). In addition, some complicating problem-specific characteristics need to be considered, such as matching care workers' medical skills with patients' requirements, continuity of care constraints and work-related constraints (e.g., a maximum number of shifts and weekends care workers are allowed to work). For all these reasons, it is clear that applying operations research (OR) techniques in HHC is a promising research field.

Current operations research literature on HHC is dominated by papers proposing models and solution methods for individual operational decision-making problems. An opportunity for improvement is the optimization of medium-term decision-making by integrating decisions while considering realistic problem aspects. Integrated studies are highly relevant because solving independent subproblems separately results in suboptimal decision-making.
In this talk, the specific problem setting we focus on is defined, and a matheuristic solution algorithm for the problem is proposed. In particular, the goal of this research is to develop innovative models and solution algorithms that enable making better overall medium-term (4-week) decision-making by considering the following decisions in an integrated manner: rostering (allocating care workers to days/shifts), assignment (assigning care workers to patients), scheduling (assigning care workers to patient visits with time specifications) and routing (determining the sequence of patient visits for each care worker). A number of important realistic problem characteristics (e.g., continuity of care and working time regulations) are included in the problem setting. A mixed integer linear programming model in this direction will be presented. The integrated solution algorithm developed to tackle the medium-term HHC planning problem first finds a feasible initial solution using a tailored k-means heuristic and a binary integer linear programming model. In the second phase of the solution algorithm, the initial solution is improved by a tailored large neighbourhood search heuristic while periodically solving a mathematical model.
Finally, the efficiency gains of tackling the medium-term HHC planning problem in an integrated manner instead of sequentially will be demonstrated, after which the results of some experiments conducted to derive insights for the practical organization of HHC will be discussed.

Analyzing the impact of integrating inventory and routing decisions in a city logistics context

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Keywords: Routing, Inventory, City-logistics

City logistics refers to the movement and distribution of goods within urban areas. Vehicle routing problem (VRP) solutions are the most frequently addressed topic in city logistics by researchers [3]. However, only a few studies consider inventory aspects along with the routing decisions, although integrating these decisions can be highly beneficial [2]. The Inventory Routing Problem (IRP) provides integrated logistics solutions by simultaneously optimizing inventory management and vehicle routing decisions. In IRP, three main decisions have to be taken: when and how much to deliver to each customer and the travel routes at each time period. Therefore, the IRP adds some complexity due to the integration of inventory and routing elements into a multi-period decision process, but may lead to better overall decisions.
While the IRP has been studied extensively, only a few studies consider inventory aspects along with the routing decisions in a city logistics context, with its specific characteristics. Examples of such characteristics include time windows, multiple vehicle trips per day, the use of heterogeneous vehicles, etc. This work addresses this gap by modeling and solving an IRP in an urban context.
This project considers and compares two scenarios: a traditional one in which inventory and routing decisions are made sequentially and an integrated one in which both decisions are made simultaneously. In the first scenario, each retailer defines its orders based on a replenishment strategy over the multi-period planning horizon. Then, the suppliers deliver their products to the city hub on the requested days, and the city hub handles the delivery process of all suppliers' products to the retailers. This involves a VRP with time windows, heterogeneous fleets, and multiple trips on each day of the planning period. In the second scenario, the city hub simultaneously determines how many products of each type will be delivered to the retailers and the delivery routes while ensuring sufficient inventory at the retailers. Therefore, the city hub simultaneously optimizes inventory and routing decisions. This results

in a multi-period IRP with multiple products, time windows, a heterogeneous fleet, and multiple trips.
For the first scenario, the inventory and routing parts are solved sequentially. The retailers decide when and how many products to receive from the suppliers in the inventory part. The retailers are assumed to use one of five different replenishment methods to determine the delivery amount for each period. For the routing part, a Large Neighbourhood Search (LNS) meta-heuristic algorithm is then used to solve the route optimization problem.
In scenario 2, the inventory and routing parts are optimized simultaneously. In addition to the delivery routes, the city hub must also specify how many products to deliver to the retailers in order to minimize the total cost. A matheuristic algorithm based on the one presented in [1] is proposed to solve this problem. We extend the algorithm to incorporate the multi-trip aspect in our problem. The matheuristic method consists of two phases: a route generation phase and an optimization phase. A set of potential delivery routes is created during the route generation phase. For this purpose, we run our LNS algorithm on the daily routing problems that result from applying the different replenishment policies considered in scenario 1 and store the routes found during the search. For the optimization phase, we present a mixed integer linear programming model to simultaneously select routes from the route pool for every period and determine the delivery quantities to the retailers for each of these selected routes. The model minimizes the total routing and inventory cost, and is solved using CPLEX. Our preliminary results show that the number of variables increases exponentially with the size of the problem, and therefore it takes a long time to solve some instances optimally using CPLEX. Hence, a column generation approach is also applied to the model.
An experimental study is conducted to compare the two scenarios. In this study, several problem characteristics are varied, including the number of suppliers, the number of retailers, the holding costs, and the replenishment method used by the retailers in scenario 1. Artificial instances that correspond to each combination are generated and solved for both scenarios. In addition to the total cost, some performance measures related to the city perspective are used for the evaluation process. With this experimental study, we aim to investigate the impact of integrating inventory and routing decisions in an urban logistics context.

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A three-phase heuristic for a capacitated vehicle routing problem with pickups, time windows and packing constraints

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Keywords: Loading, Routing, GVNS

E-commerce is expanding and as a result, the number of boxes in transit is drastically increasing. Therefore, it is important to solve the vehicle routing problem simultaneously with the loading problem, as proved in [2]. For more efficiency, retailers call on logistics service providers (LSPs) who, since the collection and delivery locations can be geographically spread, carry out the process over two days: collection of the boxes on the first day and delivery on the second. As the LSP returns to the depot between the two days, the loading plan can be changed and the collection problem can be handled separately from the delivery problem. In this work, we focus only on the collection process since it has received less attention in the literature compared to delivery process. Yet, it is subject to more uncertainty as additional pickup requests may pop up or differ from the projection during the day. Furthermore, the collection process is much more able to react to these types of disruptions on-the-fly since vehicles are initially empty.

After surveying LSPs in order to address real-life problems, they usually want to determine routes with an associated schedule and loading plan while minimising transportation distances and not exceeding their vehicle fleet size. Retailers' time windows, which often correspond to regular opening hours, and maximum working hours of the drivers must be respected. Moreover, the loading plan must be valid at each collection location, i.e. it must respect geometric, vertical stability, orientation, and sequential loading constraints. The collection problem gives rise to a Three-Dimensional Capacitated Vehicle Routing Problem with Time Windows (3L-CVRPTW).

Considering the complexity of the integration of the routing and packing problems, exact solution methods are unable to quickly generate solutions. Therefore, we

propose a three-phase heuristic to provide a good solution within a short amount of time. During the first phase, we use the savings heuristic of Clarke and Wright ([1]) to build an initial solution. If the number of routes exceeds the fleet size, a route elimination procedure is performed as a second phase. During the last phase, we apply a General Variable Neighbourhood Search ([4]) to improve the solution. We consider neighbourhoods based on typical routing operators such as relocate, swap, and crossover.
We tested our heuristic over the 600 instances from [3] modified to match the characteristics of our problem (namely, densifying customers' locations and the scaling of the boxes dimensions to fit inside the loading space vehicles). Our next step is to tune the heuristic to improve the effectiveness of our method and then to derive some managerial insights for the LSPs.

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Integration of location and inventory decisions: state of the art

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Keywords: integrated decision-making, location-inventory problem, literature review

Companies face increasing costs because of unexpected circumstances such as the COVID-19 pandemic or the war between Ukraine and Russia. In addition, end customers' needs are changing regarding delivery. Most end-customers expect express delivery from companies such as delivery within 24 hours in e-commerce or healthcare. Consequently, the supply chain performance of companies is under pressure, and companies are continuously looking for efficiency improvements. These improvements can source from different supply chain functions such as inventory, distribution, routing, location, production, and procurement [4]. Over the past years, the focus has been on improvements (e.g., cost minimization) from the perspective of one supply chain function. Although, this may result in a sub-optimal improvement as cost minimization of one supply chain function often leads to higher costs in other supply chain functions. As a result, the integration of supply chain functions has been recognized as an opportunity to improve the supply chain performance of companies [4].

Two crucial supply chain functions affecting the service level companies can offer to end customers are location and inventory. The distance between the end customer and the location where a facility (e.g., distribution center) is established determines the service level to end customers. In addition, the inventory level of the established facility impacts the service level to end customers. Therefore, a trade-off exists between the desired service level and companies' costs.

Based on [1] and [3], much research has already been done regarding the location decision, which is known as the facility location problem (FLP). Nevertheless, the integration of the location and the inventory decision, corresponding to a location-inventory problem (LIP), has received less attention in the literature. In FLPs, the number and the locations of facilities and the allocation of end customers to those facilities are determined. In LIPs, the decisions to take simultaneously are the number and the locations of facilities, the allocation of end customers to those facilities, and the optimization of the inventory service level of each established facility. Integrated decision-making, including LIP, generates more complexity. Still, it may lead to improvements in the supply chain compared to isolated decision-making (i.e., when the location and/or the inventory decision are made in isolation). The critical driver of integrating the location and the inventory decision is to achieve inventory pooling benefits. These benefits can be realized by consolidating multiple

inventory locations into a single location or a few locations. As a result, improvements can be expressed as reduced inventory costs, decreased operational costs, and efficient transportation [2]. These improvements may increase the supply chain performance of companies to deliver the expected service to end customers while dealing with tight budgets.
This study's main contribution concerns reviewing existing literature on LIP over the past decade and identifying interesting research opportunities. The insights related to our review will be combined to investigate a LIP in a healthcare context. About 30% of hospital costs are associated with logistics activities which makes logistics costs the highest cost after personnel costs. Since hospitals are labor-intensive organizations, optimizing the hospital supply chain is a relevant aspect. By analyzing the LIP in the healthcare context, the hospital supply chain may improve while ensuring a high quality of care.
Our literature review shows that few studies about LIP have been observed. Moreover, the majority consider simplified assumptions when investigating LIP. To represent real-world situations, realistic features such as multi-product, multi-sourcing of facilities, multi-echelon, and stochastic lead time, should be included in future research studies [4,1]. Furthermore, the application of LIP in most studies is investigated based on artificial data. Using real data can be a future research direction for a realistic supply chain representation. A final finding is that the type of solution method most studies use (meta)heuristic due to the complicated integration.
A mathematical formulation including more realistic features will be proposed in the future for the general LIP. Next, this model will be extended with typical healthcare features such as service level constraints, perishability, and emergency deliveries so that it can be applied in a healthcare context.

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IoT-enhanced predictive process monitoring

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Keywords: IoT-enhanced PM, predictive process monitoring, PM

Introduction IoT devices (mostly sensors) are often present around business processes (BPs), collecting data about parameters that have an impact on the process. E.g., the temperature in a refrigerated area, the presence of people in a room or the pressure in a tank can all influence BPs and their outcomes. Most of the literature focuses on deriving an event log from IoT data to apply process mining (PM) to BPs which are tracked by sensors but do not leave traces in an information system (e.g., in smart spaces) [2]. However, sensor data could also be used to contextualise processes to get a deeper understanding of their working, e.g., by using IoT context parameters in predictive process monitoring (PPM).

Challenges Several issues have to be addressed in order to use IoT data in PPM, including [2]: 1) the granularity of IoT data: often low-level, high frequency, poor semantics; 2) the scope of IoT data: IoT data can be relevant for several events/cases and 3) the dynamicity of IoT data: IoT data often have interesting values at arbitrary moments, not when something happens in the process.

Proposed approaches to tackle the challenges

Approach 1: Baseline - event/case attributes The most straightforward approach to include IoT data is to use featurisation techniques to derive event or case attributes from IoT data. Existing data-aware PPM methods can then leverage the additional attributes. The main drawback of this approach is that is takes away much of the richness of the IoT data, but it is straightforward and can give a baseline to compare with more refined approaches.

Approach 2: Take process events to IoT level A second idea is to reverse the logic of most IoT-enhanced PM and lower the granularity level of the event log instead of elevating the granularity level of the sensor data, as done in [3]. More specifically, instead of presenting a log recording when events happen, this approach would create a sort of time series of which activity is being executed at every time point (e.g., every second, every minute), as shown in Table 1. There are two issues with this

representation: 1) outcome is a categorical variable and 2) it is an impractical input for typical PPM algorithms (i.e., such a time series can be very long).

Time	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Activity	A1	A1	A1	A2	A2	A2	A2	A2	A2	A3
Sensor 1	$S1_1$	$S1_2$	$S1_3$	$S1_4$	$S1_5$	$S1_6$	$S1_7$	$S1_8$	$S1_9$	$S1_10$
Sensor 2	$S2_1$	$S2_2$	$S2_3$	$S2_4$	$S2_5$	$S2_6$	$S2_7$	$S2_8$	$S2_9$	$S2_10$

Table 1: Description of input data following approach 2.

Approach 3: Introduce context events Our final proposition is to incorporate abstracted sensor data as "context" events, e.g., temperature increase, rain starts, etc [1]. The log could contain both the context events and the process events as in Table 2, which would both be taken into account by predictive models. An issue is that the model would try to predict context events as well, based on process events. One possible solution would be to predict the context events separately and use the predictions as extra input for the model, but this requires a more complex architecture.

ID	Timestamp	Event
1	T1	Check-in complete
2	T2	Rain start
3	T3	Security start
4	T4	Security complete
5	T5	Sorter start
6	T6	Rain complete
7	T7	Traffic jam start

Table 2: Event log following approach 3.

Conclusion In this abstract, we presented various approaches to integrate IoT data in PPM, all with their pros and cons. In future works, we will apply and compare them with real-life logs enhanced with weather and industrial IoT data.

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Manifold learning in predictive process monitoring

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Keywords: Predictive Process Monitoring, Manifold Learning, Robustness

Process mining is a field of data analytics that involves extracting valuable insights from business process data generated by information systems, as a means to improve operational efficiency, reduce costs, increase productivity, and enhance customer satisfaction [1]. The aim of this field is to provide valuable insights across a range of industries and applications, from healthcare to finance, logistics, and manufacturing. Predictive Process Monitoring (PPM), a subfield of process mining, is focused on predicting different aspects of ongoing cases of business processes, including remaining time, next event, the complete remaining suffix or the outcome. In the latter field, Process Outcome Prediction (POP), data-driven approaches are used to predict the future outcomes, allowing organizations to identify potential issues and take proactive measures to prevent or mitigate them.

In recent years, increasingly sophisticated models, such as deep learning models, have been introduced to the field of POP [2]. The successful adoption of these complex models is dependent on whether they can handle and overcome malicious and adversarial inputs, as these can pose potential real-life threats, such as fraud or manufacturing failures. However, a recent study has shown that the existing models used for POP are not robust against small and insignificant adversarial attacks [3]. In addition, improved robustness against on one specific adversarial attack might introduce an improved vulnerability to another attack, highlighting the need for an extensive evaluation of the robustness of POP models against multiple, diverse, but realistic real-life adversarial attacks.

This paper introduces manifold learning to enhance the robustness against adversarial examples and generalization of POP models. The findings of this study indicate that without any defence mechanism, POP models are even vulnerable against (on-manifold) adversarial attacks that are naively engineered, highlighting the importance of defence mechanisms. Overall, on-manifold adversarial training has proven to be a more effective defence mechanism compared to regular adversarial training. The latter method often suffers from overfitting to a specific attack, thereby compromising its ability to withstand other adversarial attacks. In addition, learning from these on-manifold adversarial examples can reduce the trade-off between adversarial robustness and generalization, demonstrating that models maintain their accuracy

on new and unseen data (i.e. generalization) while being robust against worst-case adversarial attacks.
One limitation of this study is that the adversarial examples do not cover the full range of potential attacks that predictive models could encounter in real-world situations. Another limitation is that there is no overall best adversarial training technique that outperforms others in terms of adversarial robustness (or generalization). On the other hand, the study demonstrates that the success rate of on-manifold adversarial attacks is higher compared to regular adversarial training adversarial attacks. In addition, the study accounts for worst-case scenarios by evaluating white-box attacks, where the attacker possesses perfect information about the model. This therefore serves as a lower bound for the performance results. Future studies aim to explore different types of attacks and compare adversarial training with other methods to improve the robustness and generalization of POP model. Next, we will introduce a novel technique to generate artificial prefix traces from the latent space. Finally, manifold learning as a technique has potential applications in other areas, such as anomaly detection, trace clustering, and conformance checking.

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Ergodicity breaking in reinforcement learning: When expected values are not the value you expect

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Keywords: Reinforcement Learning, Decision Theory, Ergodicity Economics

Imagine being in a casino with the challenge to choose between two bets: one that guarantees a slight, fixed increase in wealth and another with a stochastic outcome where your wealth can increase significantly, or you can lose all of it. How would you explain your decision? This classic example highlights the complexities of human decision-making and has been widely used to illustrate theories on choice dynamics. In traditional economic models, decisions are often based on expected outcomes, calculated as the average outcome for a group of identical, independent agents playing the same game. However, the mathematical foundations of most theories underlying these economic models may need to be completed. These foundations are based on psychological interpretations and arguments and often involve finding the highest expected return on an outcome and assigning a mapping function to the data. The theory assumes optimizing toward the maximum expected group average is the best solution. However, this approach may only sometimes be appropriate, as it relies on the assumption of ergodicity, which assumes that time averages and ensemble averages are equivalent. Many processes in the real world do not follow this assumption, breaking ergodicity and leading to consequences that traditional economic models do not accurately capture.

Ergodicity Economics is a field of study that examines the impact of these dynamics, where optimizing toward expected values may not be the optimal strategy. By considering the dynamics of time growth and the breaking of ergodicity, precise predictions can be made with a solid mathematical foundation. This concept can also be applied to human decision-making, which often plays a central role in the dynamics described by economic science.

Furthermore, this issue has implications in the Reinforcement Learning (RL) field, which focuses on training agents to make optimal decisions and translate them into policies. The Bellman equation, a fundamental concept in RL, heavily relies on expected values. However, human decision-making only sometimes aligns with optimizing toward expected values, as predicted by ergodicity economics. In processes where time growth differs from a group average, using the group average as an expected value estimate can lead to inaccurate results.

In our work, we employ standard techniques in RL to investigate whether agents can be trained to optimize policies based on time-growth averages rather than expected

values. We apply the thought experiment from the beginning of this abstract and translate it into the realm of RL in various conceptual cases.
Our research highlights the importance of considering time growth in RL, as it can result in significantly different outcomes compared to traditional approaches that solely optimize toward expected values. Our findings demonstrate that agents can learn and optimize their policies based on time-growth averages. By incorporating the breaking of ergodicity into decision-making processes, we can gain a more comprehensive understanding of human decision-making and improve the accuracy of economic models and RL algorithms.

CBRNets: Regularizing neural networks to learn continuously-valued treatment effects from observational data

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Keywords: Causal Machine Learning, Continuously-Valued Treatments, Balanced Representation Learning

We investigate the problem of individual treatment effect (ITE) estimation for treatments with a continuously-valued dosages, i.e., individual dose responses. Such settings are prevalent in a variety of domains, from healthcare to business, economics, and beyond.
As a problem of causal inference, the individual dose response must usually be estimated from observational data. Being subject to dosage selection bias, that is, that the observed dosages are dependent on the characteristics of an observation, learning from such data is challenging. Preceding studies have fund that traditional machine learning approaches fail to generalize the dose response under dosage selection bias. Established causal machine learning approaches, such as SCIGAN, DRNets and VCNets attempt to solve those limitations. We add to this family of methods by proposing CBRNets, a novel causal machine learning approach for the estimation of dose responses. CBRNets leverages the heterogeneity of training observations to build balanced latent representations of the data to find unbiased estimates of individual dose responses.
In our work, we discuss the benefits of our method over established methods, and discuss potential use cases in business decision making and operations research. We validate the potential of CBRNets on a set of semi-synthetic experiments.

Elicitation of the weights, indifference and incomparability thresholds for the new PROMETHEE γ method.

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Keywords: PROMETHEE, elicitation, multi-criteria decision aid

Multi-criteria decision aid consists in helping decision makers to compare (rank, choose, sort, etc.) different alternatives which are evaluated on conflicting criteria. In the last decades, numerous decision aid methods have been developed. Three main categories of decision aid methods are usually considered: the aggregating, interactive and outranking methods. While aggregating methods produce a complete ranking of the set of alternatives, outranking methods usually allow some pairs of alternatives to remain incomparable.

As attested by [1], [4], the PROMETHEE methods form a widely used family of outranking procedures. These methods are based on the pairwise comparison of the alternatives and on the computation of outranking flow scores. The two most used methods of this family are PROMETHEE II which computes net flow scores leading to a complete rankings (without incomparability) and PROMETHEE I which computes positive and negative flow scores leading to partial rankings (therefore allowing incomparability relations).

Recently, an analysis of the incomparability and indifference relations produced by PROMETHEE methods has been presented in [2]. With this analysis, some shortcomings of both the PROMETHEE I and PROMETHEE II methods have been highlighted. To tackle these shortcomings, [2] presents a new method of the PROMETHEE family called PROMETHEE γ. This new method works by computing two new indicators based on the mono-criterion net flow scores of the alternatives. These indicators represent the conflicting nature of the alternatives better than the positive and negative flow scores of PROMETHEE I while leading to a preference relation consistent with the one produced by PROMETHEE II's net flow scores.
To build a preference structure, PROMETHEE γ introduces at most three additional parameters. In order to be applicable in practical decision aid problems, approaches aimed at helping the decision makers to determine these parameters must be conceived. One technique that is often used to determine the parameters of a method is elicitation. During an elicitation procedure, the decision maker is asked questions with regard to his preference between specific alternatives (also called references). The answers to these questions are then used to find a set of parameters which would

lead to the preference structure representing the preferences of the decision maker the best.
The aim of this work is to present three elicitation approaches. These three approaches are respectively based on linear programming, quadratic programming and an ad-hoc heuristic (adapted from the adaptive elicitation procedure of PROMETHEE II described in [3]). The three additional parameters required by PROMETHEE γ to produce a preference structure are an indifference, an incomparability and a preference factor threshold. In its simplest form, PROMETHEE γ produces a completely non-compensatory preference structure by using only the indifference and the incomparability thresholds. The presented approaches will therefore firstly focus on the determination of these thresholds (as well as on the determination of the weights of the criteria). Then, extensions of these approaches will be considered in order to also determine the preference threshold and to highlight the additional difficulties related to its determination.

The first presented procedure, the linear model, is the simplest one. It is based on the proportion of pairs of alternatives for which the elicitated preference parameters lead to a correct preference relation. This model is then enriched such that the "strength" of the valued preference obtained with the elicitated parameters is taken into account. This is the quadratic model. For instance, let us consider two alternatives a_i and a_j such that the decision maker states that a_i is preferred over a_j during the elicitation procedure Then, the instances of the parameters leading to stronger valued preferences of a_i over a_j are favored by the quadratic model. The linear and the quadratic models are efficient in finding a set of parameters of PROMETHEE γ reproducing the preferences of the decision maker for a set of references. However, these approaches have the drawback of not providing any insight on which references would lead to the determination of parameters reproducing the preference structure on the whole set of alternatives.

The results of the three elicitation procedures will be illustrated on different datasets. The hypothesis they rely on as well as their shortcomings will be presented.

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Analysis of third alternatives' impact in the PROMETHEE II ranking

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Keywords: PROMETHEE, Third alternative, Rank Reversal

Multi-Criteria Decision Aid (MCDA), aims to help solve problems consisting of alternatives simultaneously evaluated on conflicting criteria. Usually, three main problems are considered; to choose, to sort or to rank alternatives. In MCDA, three prominent families can be identified: aggregating, outranking and interactive procedures. This study will focus on the PROMETHEE family of outranking methods (Brans & Vincke [5]). These methods use pairwise comparison to generate a ranking of alternatives. As attested by Behzadian et al. [6] and Mareschal [7], they are widely used in practice and have been extended to sorting, clustering, group decision-making, etc. Within this family, the most used methods are PROMETHEE I which produces a partial ranking (leaving some pair of alternatives incomparable to each other) and PROMETHEE II which produces a complete ranking.

Like other outranking methods, PROMETHEE II suffers from the so-called "rank reversal" phenomenon (Keyser & Peeters [1]). The general idea is that the relative position of two alternatives in a ranking depends on one or several other alternatives (referred to as third alternative(s) in this work). Thus, removing a third alternative could change the relative position of two given alternatives causing a rank reversal. In the case of PROMETHEE II, it has been shown that rank reversal could only occur between alternatives characterized by similar scores. Such a threshold was refined on multiple occasions; Mareschal et al. [2], Verly & De Smet [3] and later by Dejaegere & De Smet [4]. Furthermore, recently, an axiomatic characterization of PROMETHEE II has been published by Dejaegere et al. [9]. It shows that the method is intrinsically related to the comparison with third alternatives and, thus, is naturally subject to rank reversal.

So far, the rank reversal phenomenon has been heavily discussed in the literature (Aires & Ferreira [8]). In this work, instead of focusing on the existence of rank reversal occurrences within PROMETHEE II, an analysis of the third alternative with respect to a pair of alternatives is conducted. The aim is to provide a way to identify third alternatives able to cause rank reversal for a specific pair. This opens the question of building alternatives causing rank reversal. Such alternatives can then be used to assess the resistance a given ranking has to rank reversal. In the end, two different approaches are used. The first considers the number of third alternatives to be added to generate rank reversal for a pair of alternatives. While, the second, provides a new threshold for rank reversal occurrence in PROMETHEE II.

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A parallel algorithm for finding the non-dominated set of multi-objective integer problems

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Keywords: Multi-objective optimization, Discrete optimization, Parallel programming

The present work aims to study an exact method for solving multi-objective integer linear programming problems (MOILP). For this purpose, a parallel approach, using multi-core CPUs with OpenMP, is developed. Indeed, the elaborated algorithm consists of taking advantage of a method that partitions the main problem into multiple subproblems, with different lower bounds. Then, all these subproblems are solved simultaneously, where each of them is assigned to a different thread, with eliminating the need to calculate all subproblems. The first series of results show relatively interesting and encouraging accelerations.

Multi-directional local search for a financial facility location problem

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Keywords: Facility location, Bi-objective optimization, Multi Directional Local Search

Introduction

Facility location models involve determining the optimal supply chain networks and the product flows in these networks. The objective function in facility location models is typically cost minimization or profit maximization. These models often ignore financial considerations linked to the future performance of the designed network. To address this gap, a model based on the Adjusted Present Value (APV) was proposed by [2]. It jointly optimizes the logistics and financial decisions. APV consists of two elements: The Operationally Generated Value (OGV) is generated by operational decisions, such as facility selection and customers allocation. The Financially Generated Value (FGV) depends on the selection of financial instruments, such as debt and equity. We propose a bi-objective optimization approach to investigate the separate impact of OGV and FGV, and a Multi-Directional Local Search (MDLS) meta-heuristic approach to solve this problem.

Multi Directional Local Search

MDLS framework, introduced by [3], is a multi-objective optimization procedure employing local search algorithms in a multi-objective framework. The principal idea of MDLS is to successively apply local search algorithms in order to optimize each of the objective functions. In each iteration, a local search algorithm is used to improve the set of non-dominated solutions with respect to each of the objectives separately. An MDLS iteration consists of (i) choosing a solution, (ii) conducting a local search on the chosen solution for each objective/direction, resulting in a new solution in each direction, and (iii) accepting or rejecting the recently produced

solutions. In this study, we propose to employ a Large Neighborhood Search (LNS) metaheuristic as the local search used in each MDLS iteration.
The efficiency of the MDLS on several multi-objective applications has been established in [3]. In the field of facility location and supply chain network, MDLS has been successfully used by [1].

Numerical experiments

We assess the quality of the proposed solution method on a set of generated benchmark instances with up to 480 customers and 48 facilities. We present the results of our MDLS implementation and prove its efficiency by comparing it with the results obtained by the ϵ-constraint method. We also show how this bi-objective model enriches decision-makers in finding trade-off solutions between earning more profit and capturing more market share.

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Unraveling interlocking vehicle trajectories towards Antwerp's largest bottleneck

Maarten Wens

This thesis provides a model to optimise vehicle trajectories, given a highway layout and a demand for trajectories that must be optimised. This model considers heterogeneous traffic, and is a mixed integer linear model. It can be used to analyse several aspects of traffic driving behaviour, but a focus is put on lane changing behaviour. The difference between cooperative driving behaviour and selfish driving behaviour is consequently analysed. This selfish behaviour can then be corrected to solve undesired characteristics, in particular the behaviour around a merging segment does not leave feasible gaps for vehicles to merge. One of the most important conclusions is that optimal behaviour is not uniquely defined, but can take many different forms which perform equally well.

Models and algorithms for segment routing optimization

Hugo Callebaut

The internet is continuously growing and consequently, the traffic routed by network operators through their networks is also growing. Network operators are therefore facing increasingly difficult challenges to handle this growing quantity of data. Upgrading a network's infrastructure is rather costly, this lead to the emergence of Traffic Engineering (TE). Traffic engineering is the branch that aims at improving the quality of service in an existing network. Traditionally networks use shortest path routing protocols, in this thesis we will focus on a new network framework called Segment Routing. We will more exactly focus on (re-)optimising the routing of the traffic using segment routing without changing the network's topology and hardware configuration.

The economical and ecological impact of a garbage collection approach using IoT

Ilias Vervaecke

One of the most significant issues in the existing garbage collection process is the lack of real-time big data for individual waste bins, resulting in inefficient garbage truck usage and hence increased fuel and time consumption. In this study, a new

method is described in which IoT technology and smart sensors are used to collect real-time data on the waste level of each bin. Our monitoring system will develop dynamic routes for garbage trucks based on this loaded level, taking into account numerous criteria such as truck and bin capacity, distance between bins, and so on. An algorithm, specifically designed for large-scale vehicle routing problems based on a decomposition strategy, is designed and consists of three phases. This issue is approached by the construction of a Mixed Integer Linear Programming (MILP) model, taking into account the problem's unique properties. The method is then put to the test in a case study based on real-world data from Ronse, a city located in Belgium. These calculations were carried out on a real dataset with over 13 000 location points. The findings of this study show that the proposed new garbage collection approach using IoT results in shorter collection times and hauling distances. Furthermore, compared to the current method, fewer containers are collected and less vehicles are needed. As a result, companies save money on waste collection while leaving a smaller ecological footprint.

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