19th ESICUP Meeting

Bologna, Italy, May 3-5, 2023

Organization

EURO
THE ASSOCIATION OF EUROPEAN OPERATIONAL RESEARCH SOCIETIES

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

EWG
ESICUP
CUTTING AND PACKING

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Thanks are given to many sponsors, who made possible the realization of this event.

ESICUP: Working Group on Cutting and Packing within EURO, the Association of the European Operational Research Societies

AIRO: Italian Association of Operations Research

DEI: Department of Electrical, Electronic, and Information Engineering "Guglielmo Marconi" of the University of Bologna

AFOSR: The Air Force European Office of Aerospace Research and Development under award number FA8655-23-1-7001

Welcome

Dear Friends, Welcome to the 19th Meeting of ESICUP - The EURO Special Interest Group on Cutting and Packing. Since its formal recognition as an EURO Working Group in 2003, ESICUP has run a series of annual meetings, which have successfully brought together researchers and practitioners in the field of cutting and packing. Previous meetings have been organised across Europe with occasional meetings further afield including Tokyo (Japan), Buenos Aires (Argentina), Beijing (China), Mexico City (México). After an online meeting due to COVID, and the last edition in Toledo (University of Castilla-La Mancha), the 19th Meeting of ESICUP will be held in Bologna, Italy.

Once again, this meeting will serve as an instrument for the development of research and the dissemination of knowledge in our field. From the scientific viewpoint, there will be thirty-four presentations, that cover many problems and aspects in the Cutting and Packing area, thus allowing for clear insights into the current state-of-the-art for this class of problems and preparing the ground for fruitful discussions.

The University of Bologna has been founded in 1088 and is the oldest University in the Western world. The prominent role of the University of Bologna was confirmed during the celebration of the 9th Centenary of the Studium, when 430 European rectors, along with 372 rectors from all over the world, signed the Magna Charta Universitatum.

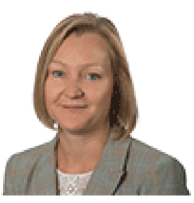
The University of Bologna is made up of 31 Departments and 5 Schools hosting more than 93,000 students ($>$ 7,000 international students) and offering 252 Degree Programmes (including 96 international Degree Programmes) and 48 PhD Programmes. Activities are split among different campuses in the region (Bologna, Cesena, Forlì, Ravenna, Rimini) and around the world (Buenos Aires).

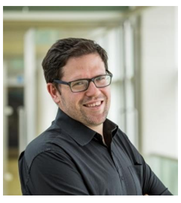
Bologna was a Roman city founded in the second century BC and reached the height of its prestige in the thirteenth century both from an economic and from a social viewpoint (for example, in 1256, Bologna was the first European city to abolish serfdom). During that period, the city experienced flourishing, as witnessed by the presence of nearly 180 towers; today, there are only 22 remaining towers, two of which being iconic symbols of the city (Torre degli Asinelli and Torre Garisenda). Bologna is unusual for the consistency of the urban structure within its medieval walls, which were built in the fourteenth century. A key feature of the city is the presence of more than 35 kilometres of porticoes, which have been playing a leading role in the city's hospitality and good living for many centuries. Bologna is officially the "City of Porticoes" following its nomination as a UNESCO World Heritage Site, as announced on 28 July 2021 directly from Fuzhou in China. Although Bologna suffered heavy bombing during World War II, its urban structure is still intact and dominates, even visually, the single architectural works of art.

Thanks to the University, Bologna quickly became known as"La Dotta" (The Learned), whereas it was in the seventeenth century that Bologna became famous for the production of many types of food, and hence named "La Grassa" (The Fat). At present, Bologna and the Emilia Romagna region are well known around the word for food, for cars and motorcycle manufacturers, and for automated industries.

Finally, we would like to express our sincere thanks to the members of both the Program Committee and the Organizing Committee, whose enthusiasm and effort was crucial for having this meeting. We wish all of you a successful conference and a very pleasant stay in Bologna!

Thank you to the organising committee and the ESICUP co-ordinating committee for their time in making this meeting happen. Julia Bennell, Antonio Martinez and Michele Monaci





Julia Bennell
University of Leeds
Program Chair

Antonio Martinez
University of Southampton
Organizer

Michele Monaci
University of Bologna
Organizer

Information for Conference Participants

Conference Venue

The conference venue will be the Aula Giorgio Prodi, which is an historical venue located in the city center, see `https://goo.gl/maps/QooXdvHJF3yKUyEL8`

About the venue

The San Giovanni in Monte complex is a historical building of the University of Bologna, ex- convent of the Canonic Laterans, restored after having been used as a prison from the Napoleonic era to 1984. The recovery became a moment for a cultural revision about the use of the building. During the renaissance the ex convent was a place of study and meditation for the city. Amongst the works from the 500', we can find the alfresco by Bartolomeo Cesi, in which we see the regal wedding from the evangelical reading of Matt,22. The alfresco can be found in the Giorgio Prodi room, which is now used as the big refectory and will, by the way, be the place where we meet!

See more: `https://disci.unibo.it/en/department/facilities/piazza-s-giovanni-in-monte-2-bologna`

Address

Piazza S. Giovanni in Monte, 2, 40124 Bologna BO

How to get to San Giovanni in Monte

The exact location is `https://goo.gl/maps/QooXdvHJF3yKUyEL8` (Piazza S. Giovanni in Monte, 2, 40124 Bologna BO). The complex is located in the historic center of Bologna, where the circulation of cars is strictly limited. Therefore, it is not recommended to arrive by private car.

Nearest bus stop Piazza Minghetti, bus lines 11, 13, 20, 90, 96

From the airport/station

Marconi Express (also called "people mover") from the Airport to the Train Station. From the Train Station, take bus line 11 until Piazza Minghetti From Piazza Minghetti: turn left and go straight along via Farini (about 400 metres), then turn right to via San Giovanni in Monte (`https://goo.gl/maps/f39ZS6fT2vipEbbz6`). In fact, if you travel in groups of 2 or 3, the taxi quickly becomes a competitive option and you will be dropped to destination in about 30 minutes.

Get-together Evening

Welcome on Wednesday will be organised in the same place (Aula Giorgio Prodi) with a catering.

Conference dinner

Cantina Bentivoglio
Via Mascarella 4/b, 40126, Bologna `https://goo.gl/maps/RvK97CXEah4gJEBr6`

Registration

The registration desk will be located in the meeting venue where you will collect your name badge and registration pack for the event.

Your name badge

You should wear your name badge at all times during the event. It is your admission to the venue (includes coffee breaks and lunch).

Equipment

The conference room is equipped with an overhead projector, a video projector and a computer.

We suggest that you bring your own computer and/or transparencies as a backup.

Length of Presentation

18 minutes for each talk, including discussion. Please note that we are running on a very tight schedule. Therefore, it is essential that you limit your presentation to the time which has been assigned to you. Session chairpersons are asked to ensure that speakers observe the time limits.

Internet Access

Further details on how to access wireless network at the conference venue will be provided on arrival.

Dietary, Mobility and Other Requirements

Please let the registration desk know if you have any additional special requirements.

Program Overview

	Wednesday 03/05/2023	Thursday 04/05/2023	Friday 05/05/2023
8:45		Registration	Session 5 (5 talks)
9:15		Opening Session	
9:30		Session 1 (5 talks)	
10:30			Coffee Break
11:00		Coffee Break	Session 6 (5 talks)
11:30		Plenary talk: Silvano Martello	
12:30		Lunch Break	Lunch Break
13:30		Session 2 (5 talks)	Session 7 (5 talks)
15:00		Coffee Break	Closing Session
		Session 3 (5 talks)	Guided Tour Bologna
17:00		Short break	
17:30		Session 4 (4 talks)	
18:30			
19:00	Get Together		
19:30		Conference Dinner	
21:00			

Scientific Program Schedule

Thursday

9:20 – 9:30

Opening Session *Julia Bennell and Michele Monaci*

9:30 – 11:00

Session 1 *Chair: Julia Bennell*

1.1 – An efficient triangle mesh collision detection approach to three-dimensional irregular open dimension problems
Jonas Tollenaere, Tony Wauters

1.2 – Quasi-Packing spheres with ratio conditions
Tetyana Romanova, Andreas Fischer, Igor Litvinchev, Georgiy Yaskov, Petro Stetsyuk, Oksana Melashenko

1.3 – Methodology of solving packing problems using the Phi-Function technique
Sergey Shekhovtsov, Yuri Stoyan, Andrey Chugay, Tatiana Romanova, Vladimir Dubinsky

1.4 – Extending the semi-discrete representation to 3D nesting problems
Sahar Chehrazad, Dirk Roose, Tony Wauters

1.5 – Optimized packing non-spherical powder particles
Alexander Pankratov, Stoyan Yuri, Tetyana Romanova, Igor Litvinchev, Zoia Duriahina, Igor Lemishka, Sergiy Maximov

11:30 – 12:30

PLENARY TALK *Chair: Michele Monaci*

– Quadratic Knapsack Problems
Silvano Martello

13:30 – 15:00

Session 2 *Chair: Rosephine Georgina Rakotonirainy*

2.1 – The min-Knapsack Problem with Compactness Constraints
Alberto Santini, Enrico Malaguti

2.2 – Parallel dynamic programming algorithms for large-scale two-dimensional guillotine cutting
Adriano Masone, Mauro Russo, Claudio Sterle

2.3 – Dealing with stochastic defects in 2D cutting stock problem applied to the Home Textile industry
Khadija Hadj Salem, Kseniya Schemeleva,Xavier Delorme, and José Fernando Oliveira

2.4 – The k-Best Solutions of the 0-1 Knapsack Problem: Algorithms and Applications
Marco Antonio Boschetti, Stefano Novellani

2.5 – On solving the generalised bin packing problem using multi-objective goal programming approach
Rosephine Georgina Rakotonirainy

15:30 – 17:00

Session 3 *Chair: Antonio Martinez-Sykora*

3.1 – Arc flow approach for the multiperiod cutting stock problem with alternative manufacturing modes
Heloisa Vasques da Silva, Silvio Alexandre de Araujo

3.2 – Combinatorial Benders Decomposition for the Two-Dimensional Bin Packing Problem
Jean-François Côté, Mohamed Haouari, Manuel Iori

3.3 – Automatic Storage Design
Luis Marques, François Clautiaux, Aurélien Froger

3.4 – Arcflow formulations and constraint generation frameworks for the two-bar charts packing problem
Mathijs Barkel, Maxence Delorme

3.5 – Procedural bilevel programming: applications to the bin packing problem
Toni Martinez-Sykora, Stefano Coniglio, Tony Wauters

17:30 – 18:30

Session 4 *Chair: Jose Fernando Oliveira*

4.1 – Cutting and unloading: management of a work center in iron manufacturing
Fabrizio Marinelli, Andrea Pizzuti

4.2 – Packing problems in e-commerce
Ramon Alvarez-Valdes, Francisco Parreño, Teresa Alonso

4.3 – Cutting problems in the ornamental stone industry
Maria Antónia Carravilla, José Fernando Oliveira, Rui Guerreiro, Fernando Sousa

4.4 – Incorporating Overcuts into a Mathematical Programming Model for 2D Rectangular Cutting Problems
José Fernando Oliveira, Maria Antónia Carravilla

Friday

9:00 – 10:30

Session 5 *Chair: Tony Wauters*

5.1 – The Problem of Optimal Placement under Relaxed Conditions of Non-intersection of Geometric Objects
Sergiy Yakovlev, Oleksii Kartashov, Dmytro Podzeha, Iryna Yakovleva

5.2 – A new family of mixed-integer programming models for irregular strip packing based on vertical slices and feasibility cuts
Juan J. Lastra-Díaz, M. Teresa Ortuño

5.3 – Exact and Heuristic Methods for a 2D Bin Packing Problem in the Sheet Metal Industry
Luigi De Giovanni, Nicola Gastaldon, Chiara Turbian

5.4 – Two-dimensional strip packing problem relaxations
Fatih Burak Akcay, Maxence Delorme

5.5 – A new guided local search heuristic and fast-fail collision-detection system for 2D irregular cutting and packing problems
Jeroen Gardeyn, Tony Wauters

11:00 – 12:30

Session 6 *Chair: François Clautiaux*

6.1 – Decomposition approaches for a container loading problem with stacking constraints and medium-sized weakly heterogeneous items: an empirical study
Maxence Delorme and Joris Wagenaar

6.2 – Instance Space Analysis for 2D Bin Packing Mathematical Models
Chang Liu, Kate Smith-Miles, Tony Wauters, Alysson Costa

6.3 – Mixed Integer Linear Optimisation models for the 2D Cutting Stock Problem with Variable Sized stock
Paula Terán Viadero, Antonio Alonso-Ayuso, Javier Martín Campo

6.4 – A Support Planes Beam Search Algorithm for the Pallet Loading Problem
Davide Croci, Ola Jabali, Jacopo Libè, Federico Malucelli

6.5 – A novel reformulation for the single-sink fixed-charge transportation problem
Robin Legault, Jean-François Côté, Bernard Gendron

13:30 – 15:00

Session 7 *Chair: Elsa Silva*

7.1 – Irregular 3D multi-part production in additive manufacturing
Pedro Rocha, António Ramos, Elsa Silva

7.2 – Deep Reinforcement Learning for Combinatorial Problems: A new approach for the 3DBPP container loading problem in logistics
Justine Evers, Michaël Schyns

7.3 – A three-phase heuristic for a capacitated Vehicle Routing Problem with pickups, time windows and packing constraints
Emeline Leloup, Célia Paquay, Thierry Pironet

7.4 – Challenges of container loading problems in logistics automation
António G. Ramos, Elsa Silva

7.5 – How to include stability as a constraint in a MILP model for the Manufacturer's Pallet Loading Problem
Elsa Silva, António Ramos, João Araújo, Ana Moura

15:00 – 15:10

Closing Session *Tony Wauters and Michele Monaci*

Social Program

- **Welcome - Wednesday 3rd of May**
  Welcome will be organised in the same place (Aula Giorgio Prodi) with a catering.

  Catering begins at 7 PM
  A registration desk will be available.

- **Thursday 4th of May**

  Social dinner will be at the Cantina Bentivoglio, Via Mascarella 4/b, 40126, Bologna
  `https://goo.gl/maps/RvK97CXEah4gJEBr6`

  Meeting time 8 PM

- **Friday 5th of May**

  A guided tour of Bologna center, starting from Piazza Maggiore and including the Archiginnasio, the old market in the Quadrilatero and the Clock Tower, will be organized on Friday afternoon right after the end of the meeting.

Abstracts

Plenary Talk

Quadratic Knapsack Problems

Silvano Martello*

* *Alma Mater Studiorum Università di Bologna, Bologna (Italy)*

Inspired by a number of real-world applications explored since the Seventies in different fields, the Quadratic Knapsack Problem was formally defined in 1980 as a 0-1 quadratic problem. The problem did not attract much attention over the next ten years, while a consistent stream of research started in the Nineties. In the first part of this presentation we discuss the main classical results, ranging from exact solutions methods and convex quadratic relaxations to heuristics, matheuristics, and metaheuristic algorithms. We conclude by presenting on-going reasearch trends on some relevant variants of the problem.

Keywords: quadratic knapsack; relaxations; heuristics

1.1

The min-Knapsack Problem with Compactness Constraints

Alberto Santini*, Enrico Malaguti†

* *Department of Information Systems, Decision Sciences and Statistics, ESSEC Business School and Institute of Advanced Studies, Cergy Paris Université, 3 Avenue Bernard Hirsch, 95021 Cergy (France)*

† *Dipartimento di Ingegneria dell'Energia Elettrica e dell'Informazione "Guglielmo Marconi", Universita di Bologna, Viale del Risorgimento, 2, 40136 Bologna (Italy)*

In the min-Knapsack problem, one is given a set of items, each having a certain cost and weight. The objective is to select a subset with minimum cost, such that the sum of the weights is not smaller than a given constant. In this paper we introduce an extension of the min-Knapsack problem with additional "compactness constraints" (mKPC), stating that selected items cannot lie too far apart from each other. This extension has applications in algorithms for change-point detection in time series (the PRISCA algorithm, see Lorenzo Cappello and Oscar Hernan Madrid Padilla (2022). *Variance change point detection with credible sets.* arXiv: 2211.14097) and for variable selection in high-dimensional statistics (the SuSiE algorithm, see Gao Wang et al. (2020). *A simple new approach to variable selection in regression, with application to genetic fine mapping.* Journal of the Royal Statistical Society: Series B (Statistical Methodology) 82 (5), pp. 1273–1300. doi: 10.1111/rssb.12388). We propose three solution methods for the mKPC. The first two methods use the same Mixed-Integer Programming (MIP) formulation, but with two different approaches: either passing the complete model with a quadratic number of constraints to a black-box MIP solver or dynamically separating the constraints using a branch-and-cut algorithm. Numerical experiments highlight the advantages of this dynamic separation. The third approach is a dynamic programming labelling algorithm. Finally, we focus on the special case of the unit-cost mKPC (1c-mKPC), which has a specific interpretation in the context of the statistical applications mentioned above. We prove that the 1c-mKPC is solvable in polynomial time with a different ad-hoc dynamic programming algorithm. Experimental results show that this algorithm vastly outperforms both generic approaches for the mKPC, as well as a simple greedy heuristic from the literature.

Keywords: cutting; knapsack problems; applications in statistics; dynamic programming

1.2

A new family of mixed-integer programming models for irregular strip packing based on vertical slices and feasibility cuts

Juan J. Lastra-Díaz*, M. Teresa Ortuño*

**Department of Statistics and Operational Research, Institute of Interdisciplinary Mathematics, UCM Research Group HUMLOG, Complutense University of Madrid, Spain*

The irregular strip-packing problem, also known as nesting or marker making, is defined as the automatic computation of a non-overlapping placement of a set of non-convex polygons onto a rectangular strip of fixed width and unbounded length, such that the strip length is minimized. Nesting methods based on heuristics are a mature technology, and currently, the only practical solution to this problem. However, recent performance gains of the Mixed-Integer Programming (MIP) solvers, together with the known limitations of the heuristics methods, have

encouraged the exploration of exact optimization models for nesting during the last decade. Despite the research effort, there is room to improve the efficiency of the current family of exact MIP models for nesting. In order to bridge this gap, this work introduces a new family of continuous MIP models based on a novel formulation of the NoFit-Polygon Covering Model (NFP-CM), called NFP-CM based on Vertical Slices (NFP-CM-VS). Our new family of MIP models is based on a new convex decomposition of the feasible space of relative placements between pieces into vertical slices, together with a new family of valid inequalities, symmetry breakings, and variable eliminations derived from the former convex decomposition, which include a family of feasibility cuts among three pieces for the first time in the literature. Our experiments show that our new NFP-CM-VS models outperform the current state-of-the-art MIP models. Ten open instances are solved up to optimality within one hour for the first time, including one with 27 pieces.
Keywords: Packing; Integer programming; Irregular strip packing; Nesting; Cutting

1.3
On solving the generalised bin packing problem using multi-objective goal programming approach

Rosephine Georgina Rakotonirainy*
**Department of Statistical Sciences, University of Cape Town, South Africa*

In the generalised bin packing problem, the objective consists of loading a set of profitable non-compulsory rectangular items together with a set of compulsory rectangular items in a non-overlapping manner into the appropriate bins such that the resulting total cost is a minimum. The total cost is given by the difference between the total cost of the selected bins and the total profit of the loaded items. The problem generalises various bin packing problems sought in the literature, including the variable cost and size bin packing problems and brings innovation in the area of airfreight transportation where it can describe the fundamental role played by the trade-off between shipping costs and item profits.
In this work, the problem is modelled as a multi-objective problem with respect to two conflicting design objectives involving minimization of the number of bins used or the costs associated to the selected bins and maximization of the profits of packed items. A weighted goal programming model is formulated and presented. A hybrid simulated annealing algorithm is developed to solve the problem. The proposed algorithm was tested on a set of benchmark instances available in the literature. The computational results have validated significance and usefulness of the proposed approach.
Keywords: generalised bin packing problem; multi-objective goal programming

1.4
The Problem of Optimal Placement under Relaxed Conditions of Non-intersection of Geometric Objects

Sergiy Yakovlev*, Oleksii Kartashov*, Dmytro Podzeha*, Iryna Yakovleva†
** Mathematical Modelling and Artificial Intelligence Department, National Aerospace University, Kharkv Aviation Institute, Ukraine*
† Department of Computer Science and Information Technology, National University of Urban Economy in Kharkiv, 17 Marshala Bazhanova st., 61002, Kharkiv, Ukraine

In this paper, a class of placement problems of arbitrary shape geometric object under relaxed conditions on their pairwise non-intersection is considered. Such problems are intermediate between the well-known classes of packing and covering problems and are widely used, especially in territory monitoring systems. Various mathematical models of these problems are described depending on the rigidity of the requirements of non-intersection of objects. An original approach to the statement of packing and covering problems is proposed, based on the study of the dependence of the intersection area of objects on the parameters of their placement. As a result, the problem is formulated as a nonlinear optimization problem with a specific system of constraints. The main attention in the report is given to the placement of objects of circular shape. In this case, one can write analytical formulas both for the objective function, its gradient, and for the system of constraints and the corresponding Jacobians. On this basis, a comparative analysis of local optimization methods was carried out, and approaches for improving local extrema were also described. The experimental results are illustrated by a large number of relevant figures and tables.
Keywords: placement problem; geometric object; mathematical model; optimization; circular shape

1.5

Arc flow approach for the multiperiod cutting stock problem with alternative manufacturing modes

Heloisa Vasques da Silva*, Silvio Alexandre de Araujo†

**São Paulo State University (UNESP), Avenida Eng. Luís Edmundo Carrijo Coube, 14-01, Vargem Limpa, Bauru-SP, Brasil- CEP 17033-360, Brazil*

†São Paulo State University (UNESP), Rua Cristóvão Colombo, 2265, Jardim Nazareth, São José do Rio Preto-SP, Brasil CEP 15054-000, Brazil

In the one-dimensional cutting stock problem with alternative manufacturing modes (1D-CSP-AM), objects with different thicknesses must be cut to manufacture products characterized by multiple manufacturing modes. Each manufacturing mode is described by a combination of items with varied lengths and thicknesses. The motivation of the study was the cutting process of steel bars in the concrete industry, in which a technical requirement of shear force can be met with different combinations of item lengths and thicknesses. The aim is to minimize the total cost of raw material, i.e., steel bars. In this work, we extend the 1D-CSP-AM to the multiple-period case, considering the inventory cost of items and final products. To this, we use the arc flow formulation to model the cutting stock problem and the meet-in-the-middle approach to generate the arc set. The aim is to minimize the costs of raw materials and inventories. The one-dimensional cutting stock problem is modeled as a minimum flow problem in an acyclic directed graph, where vertices represent positions in the object and arcs connecting vertices represent the cut of an item or waste of material in a position. This model has many symmetrical solutions and the computational behavior depends on the number of arcs. The meet-in-the-middle approach reduces the set of arcs by aligning cutting patterns from a determining position in the object and eliminating the repeated ones. To explore the performance of the model, a set of 90 instances based on the literature was proposed, including data on planning horizons and inventory costs and combining parameter variations in the number of periods (5, 10), the number of items (20, 30, 40), and the size of items (small, large, varied). The experiments were performed on a computer with 16GB RAM and an Intel Core i7 processor, using CPLEX 12.10 as a solver and OPL as a coder. The data was submitted to the model with a time limit of 300s (5 min) for each instance to find an integer solution. We collect bounds (upper and lower), gaps, solution times, and the number of variables and constraints for each instance. The computational results show reasonable gaps and computational times for the instances considered.

Keywords: Integer programming; Mathematical modeling; Industrial applications

1.6

Cutting and unloading: management of a work center in iron manufacturing

Fabrizio Marinelli*, Andrea Pizzuti*

* *Dipartimento di Ingegneria dell'Informazione – Università Politecnica delle Marche, Italy*

This work addresses an industrial case study emerging from an ongoing project with a prominent firm, leader in the design and production of manufacturing work centers for cutting iron bars in the reinforcement processing. The work center is a complex system comprising several components and demanding the effective implementation of multiple operative steps. A sequential cutter is supplied with batches of iron bars according to pre-computed cutting stock patterns. The parts obtained are then shifted through a conveyor belt and collected in homogeneous lots into two temporary left and right unloading stations. The lots are moved and consolidated into orders to a stocking area, composed of identical parallel buffers, by means of two portals able to perform only lengthwise movements. On requests from the downstream departments, the portals move the consolidated orders to unloading tracks from which they leave the work center.

Stops of the guillotine cutter, occurring when the unloading stations cannot take new incoming parts, translate into idle times of the work center. The minimization of idle times asks for the effective use of the unloading stations, buffers, and portals.

An evolutionary three-steps optimization algorithm is presented: in the first step, a pattern sequencing problem aiming at minimizing the order spread is approached by means of a local search. Then, in the second step, a branch-and-bound procedure computes the dispatching of parts on the temporary unloading stations (side and position within the station) in order to minimize cutter breaks, number of portal translations, and side mismatches of parts. Finally, in the third step, a sequential value correction (SVC) heuristic computes the dynamic packing of the lots into the stocking area. An integer linear program for such a peculiar packing problem, whose structure was also exploited in the design of the SVC, is presented. The algorithm provides a collection of non-dominated solutions with respect to a number of objective functions including the number of cutter stops, the order spread and fragmentation, and the number of portal loading/unloading operations. A preliminary computational experience on representative industrial instances was carried out and results are discussed to highlight the viability of the proposed approach.

Keywords: Cutting process; Industrial application; evolutionary algorithm; SVC algorithm

1.7

Arcflow formulations and constraint generation frameworks for the two-bar charts packing problem

Mathijs Barkel*, Maxence Delorme*

*Department of Econometrics and Operations Research, Tilburg University, 5037 AB Tilburg, The Netherlands

We consider the two-bar charts packing problem (2-BCPP), a recent combinatorial optimization problem whose aim is to pack a set of one-dimensional items into the minimum number of bins. As opposed to the well-known bin packing problem, pairs of items are grouped to form bar charts, and a solution is only feasible if the first and second items of every bar chart are packed in consecutive bins. After providing a complete picture of the connections between the 2-BCPP and other relevant packing problems, we show how we can use these connections to derive valid lower and upper bounds for the problem. We then introduce two new integer linear programming (ILP) models to solve the 2-BCPP based on a non-trivial extension of the arcflow formulation. Even though both models involve an exponential number of constraints, we show that they can be solved within a constraint generation framework. We then empirically evaluate the performance of our bounds and exact approaches against an ILP model from the literature and demonstrate the effectiveness of our techniques, both on benchmarks inspired by the literature and on new classes of instances that are specifically designed to be hard to solve. The outcomes of our experiments are important for the packing community because they indicate that arcflow formulations can be used to solve targeted packing problems with precedence constraints and also that some of these formulations can be solved with constraint generation.

Keywords: bin packing; two-bar charts; integer programming; arcflow formulation; constraint generation

1.8

Decomposition approaches for a container loading problem with stacking constraints and medium-sized weakly heterogeneous items: an empirical study

Maxence Delorme*, Joris Wagenaar*

*Department of Econometrics and Operations Research, Tilburg University, The Netherlands

We consider a real-world (three-dimensional) truck loading problem where the objective is to maximize the value of the items packed into a single truck. While container loading problems have been extensively studied in the literature, our case study contains a set of features that was not often considered together in previous research papers. Indeed, in the version of the problem we investigate, (i) items can be rotated by 90 degrees (i.e., the width and the length of an item are interchangeable, but not the height), (ii) items can be stacked on top of each other to form a column of items (stackability is captured by a compatibility graph where an arc (i, j) belongs to the graph if item j can be stacked on top of item i), and (iii) items are weakly heterogeneous (an instance typically contains 5 or 6 distinct pairs of item width and length) and have medium size (the truck can accommodate around 15×3 columns of items). The problem is particularly interesting as it mixes a packing component (the column layout in the truck) together with a matching component (the items that compose the columns).

We first study the performance of a sequential approach where one generates the columns of items in a first stage and then solves a 2-dimensional knapsack problem afterwards. We then study the performance of the integrated approach where both sets of decisions are taken simultaneously. We introduce a compact integer programming model to solve the problem exactly, and follow afterwards the path of other researchers who suggested using Benders' decomposition to solve such a large-sized model. We identify three ways to decompose the problem and we observe trough an extensive set of computational experiments on both real and randomly generated instances that one decomposition is more competitive than the others. We conclude our work by outlining relevant extensions of the problem related to packing stability and customer visit order.

Keywords: Container loading problem; strip packing problem; Benders' decomposition

1.9

Exact and Heuristic Methods for a 2D Bin Packing Problem in the Sheet Metal Industry

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We consider an optimization problem of practical relevance arising in Salvagnini Italia, a multinational corporation working in the sheet metal industry. The problem asks for determining efficient cutting layouts that minimize the waste material under technological constraints emerging from the context. Among them, hard and soft precedence relations between groups of items are taken into account, meaning that a production order has to be determined for material sheets, as well as conditional safety distances between items to preserve the quality of the products. This problem belongs to the class of Two-Dimensional Bin Packing Problems (2DBPP), and several variants have been proposed during the last decades in the Operations Research literature. Nevertheless, the problem under study presents a set of practical attributes that, to the best of our knowledge, has never been considered yet. We present exact and heuristic algorithms to solve the problem, both keeping into account all the technological constraints and both based on solving Mixed Integer Linear Programming (MILP) models. The proposed procedures have been tested on instances of practical relevance, and computational results will be presented, with a particular focus on the comparison between the proposed methods and the current company's procedure.
Keywords: 2D-Bin Packing; Sheet Metal Industry; Mixed Integer Linear Programming; Metaheuristic; Precedence Constraints

1.10

Two-dimensional strip packing problem relaxations

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In the two-dimensional strip packing problem (SPP), one wants to pack a set of rectangular items into a strip with fixed width such that the height of the resulting packing is minimized. The items must not overlap and must be packed with their edges parallel to the borders of the strip. The SPP is a strongly $\mathcal{NP}$-hard problem that is difficult to solve in practice. Indeed, some instances with as few as 20 items cannot be solved to optimality, even by the most competitive approaches. Those competitive approaches include branch-and-bound algorithms, mixed integer linear programming (MILP) models, and Benders' decomposition algorithms, the latter demonstrating the best empirical performance.
Benders' decomposition algorithms proposed in the literature formulate the master problem as a parallel processing scheduling problem with contiguity constraints ($\mathrm{P}|cont|\mathrm{C}_{\max}$), and use a (scheduling) slave problem to transform a solution of the master problem into a feasible solution of the SPP. Even though various sets of computational experiments showed that most of the running time was spent solving the master problem, very few research papers (if any at all) focused on developing efficient techniques to solve ($\mathrm{P}|cont|\mathrm{C}_{\max}$). Instead, the literature has mostly focused on the one dimensional contiguous bin packing problem (1CBP), a problem closely related to ($\mathrm{P}|cont|\mathrm{C}_{\max}$) but that is less suitable to serve as a master problem. Therefore, this work aims to gather and enhance the existing knowledge about ($\mathrm{P}|cont|\mathrm{C}_{\max}$) and the 1CBP, with a primary focus on the former problem. After reviewing the MILP models that have been proposed in the literature, we study how recent cutting and packing advances such as the so-called "meet-in-the-middle" patterns, "reflected arcs", and "reduced-cost variable fixing" may be used to enhance the performance of these models. We also introduce two new exact approaches for solving ($\mathrm{P}|cont|\mathrm{C}_{\max}$) and the 1CBP: a constraint programming approach and a pattern-based approach. We compare the performance of the resulting algorithms through a comprehensive empirical study and identify the methods that yield the best results.
Keywords: Contiguous bin packing; strip packing problem; exact approach

1.11

A three-phase heuristic for a capacitated Vehicle Routing Problem with pickups, time windows and packing constraints

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Retailers are offering increasingly widespread e-commerce services and the number of boxes sent via a service carrier is dramatically growing. Therefore, efficient loading of the boxes during transportation is crucial in the development of the routes and this arrangement must be optimised simultaneously with the visit of the customers during their period of availability, i.e. their time window. Since the collection and delivery points can be geographically spread, carriers perform the process over two days: on the first day, they collect the boxes and on the second day, they deliver them. The return to the depot between the two days allows them to separate the pickup operations from the delivery operations. In this work, we focus only on the collection of boxes since it has

received less attention in the literature compared to delivery while it is subject to more uncertainty as additional pickup requests may pop up, or the number of boxes to collect can change during the day. Furthermore, the collection process, in which the vehicle is initially empty, is much more able to react to these types of disruptions on-the-fly. The collection problem gives rise to a Three-Dimensional Capacitated Vehicle Routing Problem with Time Windows (3L-CVRPTW). In order to deal with real-life problems, we conduct a survey among Belgian transportation service providers with a consulting group. They expect to be able to provide routes with respective schedule and loading plan while minimising transportation distances and not exceeding their own vehicle fleet. The schedule must respect the time windows and a maximum working duration, whereas the loading plan must be valid at each customer location and satisfy some constraints (namely, geometric, vertical stability, orientation, and multi-load constraints). Considering the complexity of the integration of the routing and packing problems, off-the-shelf solvers are unable to quickly generate solutions. Therefore, we are currently developing a three-phase heuristic to provide a good solution in a short time. The first step consists in building an initial solution via the savings heuristic of Clarke and Wright. The second step is a route elimination procedure in order to reduce the number of routes if it exceeds the fleet size. In the last step, we try to improve the solution via a General Variable Neighbourhood Search. The neighbourhoods are based on typical routing operators such as relocate or swap in inter and intra routes, and the crossover. We tested our heuristic on 600 instances from the literature. Based on our first experiments, we observed an average improvement of 5the solution, whereas the computation time decreases with the number of customers. Our next step is to tune the heuristic and then compare it to existing algorithms to check the effectiveness of our method.
Keywords: Loading; routing; time windows; GVNS

1.12

Challenges of container loading problems in logistics automation

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Logistics has undergone a huge transformation over the last two decades, driven by the growth of e-commerce and continuous search for higher service levels. This change has also been accompanied by an increasing challenge of providing more sustainable operations, with a strong focus on freight transportation due to its contribution to greenhouse gas emissions. The growing labour shortage has added to this growing complexity. All these factors combined have led the sector to automate its operations, with a particular focus on distribution and fulfilment centres. Case picking has increased due to e-commerce and the adoption of different JIT type of logistics strategies, resulting in an increase in the number of pallets handled and shipped from warehouses. Besides the increase in number, the type of pallet has shifted, moving from pallets composed of uniform cases and low heterogeneity cases to mixed-case pallets. The problem of determining the placement of a set of heterogeneous boxes in a pallet has been addressed in the literature as the container loading problem, the pallet loading problem, or the mixed-case palletization problem, but other designations for the problem can also be found. The goal is to maximize the usage of the volume of the pallet, while compiling with a set of constraints such as the non-overlapping of boxes and the positioning of the boxes within the virtual walls of the pallet. Additional practical constraints can be applied, such as the stability of the boxes or the pallet weight limit. As the opportunities for automated palletizing and automated depalletizing of pallets grow, it is necessary to identified what are the practical constraints that arise in the container loading problem as a result of the automation of warehouses. This work provides the results of the requirement gathering phase for the SmartlL - Intelligent interoperable robotic intralogistics and the FlexibleRoboticSolutions - Intelligent, Compact and Flexible End of Line Robotic Solutions projects.

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Keywords: Mixed-case Pallet loading; Logistics; Automation

1.13

Mixed Integer Linear Optimisation models for the 2D Cutting Stock Problem with Variable Sized stock

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The work presented is developed in collaboration with a Spanish company in the honeycomb cardboard sector. This Company has as its main objective in the medium term to automatise its processes to gain efficiency and effectiveness. In order to help them in their decision-making process we have developed different mathematical optimisation models. The company serves items of different sizes with high variability in terms of dimensions (widths and lengths) and demands. For this purpose, they have a machine to produce the panels and the machines required to cut them in the smaller items. As the production process is controlled from beginning to end, they can decide which panels produced and how to cut them. This special point of flexibility in terms of panel production guide us to a version of the CSP where the stock is considered variable sized. Mixed Integer Linear Optimisation (MILO) models are presented. Having the reduction of the leftover material as the main objective, the decisions to make are (1) how many panels to produce, (2) their dimensions, and (3) how to cut them. The models have been validated using real data from de company, obtaining really good results that drastically reduce the amount of leftover material used, which has as a direct consequence on the reduction of operating times and economic costs.
Keywords: Mixed Integer Linear Optimisation; Cutting Stock Problem; Variable Sized stock; honeycomb cardboard

1.14
Packing problems in e-commerce

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E-commerce has experienced a huge increase in recent years. Large com-panies receive thousands of orders every day. These orders are sent to their logistics centers, where the products for each order are first picked from the storage area, then sent to the packing area, and finally shipped to the customer. Leaving aside other logistic issues, we focus on the packing side of the process. Two main problems arise. First, the strategic problem of choosing the set of boxes with a given cardinality best suited to pack a set of orders (taken from the company's past data or estimated from an appropriate probability distri-bution). This problem is known in our field as the assortment problem and is critical because companies use millions of boxes of each type every year. The cardinality of the set is determined to reach a balance between packing efficiency (for which the more box types the better) and the stock and cost considerations (fewer box types bought in larger quantities are cheaper and easier to maintain in storage). The second problem is the operational problem the packer has to solve for each order. Once the products are on the packer's table, the packer has to decide in which box or set of boxes the products fit and in which position they are packed. This is basically a 3D bin packing problem with multiple bin sizes. Initially, these decisions were left to the packer, who was given some training. However, companies realized that they needed automatic, efficient, and very fast solutions. For each company, the objectives and constraints depend on the type of products sold. In some cases, a simple objective of minimizing the volume of the boxes and simple non-overlapping constraints are enough. In other cases, such as in the clothing industry, there are very specific rules about the order and the position of each product inside the box, and the objectives can include other criteria such as not sending boxes of very different sizes. In this talk we will discuss our experience with a large clothing company, describing the problem and the algorithmic approach.
Keywords: e-commerce, packing, assortment, bin packing

1.15
A new guided local search heuristic and fast-fail collision-detection system for 2D irregular cutting and packing problems

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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.

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

1.16

Automatic Storage Design

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Automated storage and retrieval systems have been studied for years in the context of warehouse optimization. The number of shelves and their height is generally determined in such a way that the number of retrieval operations per minute is maximized, i.e., response time is often more important than the space used by the device. In our specific study, we consider the case where capacity is highly constrained, and the efficiency of the system is not an issue. We call our problem the *Automatic Storage Design* (ASD) problem.

In the ASD problem, the goal is to design a set of shelves in a box, design a set of compartments in every shelf and assign items to the compartments, where deciding to assign an item is associated with a profit. The objective is to maximize the total profit. The design parts are defined on a set of packing constraints, i.e., the sum of the shelves' heights must not exceed the box's height and the sum of compartments' widths in every shelf must not exceed the box's width. The assignment part is defined on a set of temporal knapsack constraints, i.e., the items must fit with respect to their height, width, length and time windows. For an item to be a candidate for assignment in a compartment, its height must be less than or equal to the compartment's height and its width must be equal to the compartment's width. The length dimension represents the knapsack constraint, i.e., the sum of items' lengths with respect to their time windows must not exceed the compartment's length. This problem generalizes the temporal knapsack problem, and the three-dimensional three-stage guillotine cutting problem.

We consider several formulations based on integer linear programming (ILP) and dynamic programming. We present a compact ILP formulation serving as a reference point. We formulate the ASD problem as a dynamic program with additional constraints and show that it is equivalent to the search for a max-cost flow in an directed acyclic hypergraph. From this representation, we derive an ILP flow-model and a label setting algorithm. In order for our methods to be as competitive as possible, we introduce several preprocessing procedures to reduce the size of the hypergraph.

Extensive numerical studies are performed on a set of 320 randomly generated instances to assess the efficiency of our methods and compare them with each other. We also evaluate the impact of the design and the temporal knapsack aspect of the problem on the results.

Keywords: Cutting and Packing; Three-dimensional knapsack; Temporal knapsack; Dynamic programming; Integer linear programming; Arc-flow models; Hypergraphs

1.17

Instance Space Analysis for 2D Bin Packing Mathematical Models

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It is infamously difficult to assess algorithm performance objectively. The standard practice of reporting algorithms39; "on average" performance across test instances can lead to misleading conclusions if the instances39; diversity and suitability are not scrutinized. An algorithm that performs well on a specific set of problem instances is not guaranteed to do well with different instances. Merely considering average performance does not provide insight into an algorithm39;s strengths and weaknesses. Recently, the Instance Space Analysis methodology has been developed to provide a robust framework for analyzing algorithm performances. This methodology projects problem instances onto a 2D space called instance space, achieved by calculating features of the instances and determining an optimal mapping from these features to 2D space. The relationships between algorithm performances and selected features of problem instances can be calculated and presented visually in instance space, and each algorithm's strengths and weaknesses can be identified. Using machine learning techniques, an algorithm39;s performance on a given problem instance can be predicted by projecting the instance onto instance space. The suitability of the features selected and test instances considered can be assessed. This talk applies the methodology to the 2D Bin Packing Problem, a classic cutting and packing problem. For the first time, Instance Space Analysis is applied to mixed-integer linear programming (MIP) models. MIP formulations of the 2D Bin Packing Problem are treated as our "algorithms." Their performance will be assessed by whether the MIP solver CPLEX can solve the models. Each model39;s strengths and weaknesses can be identified in instance space, along with the features that best distinguish these regions. Ultimately, this analysis will provide insight into the structure of the 2D Bin Packing Problem and factors affecting the solvability of MIP models.
Keywords: 2D Bin Packing; Mixed Integer Linear Programming Models; Instance Space Analysis

1.18

Procedural bilevel programming: applications to the bin packing problem

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The assumption of a follower solving their optimization problem to optimality is key to bilevel optimization. In practical applications, though, where the follower's problem is typically solved by a human, it is arguably very rare that the follower would always find an optimal solution. Motivated by this observation, we introduce a new bilevel optimization paradigm, which we refer to as ""procedural bilevel programming"", where the follower, rather than seeking an optimal solution to their problem, applies a well-defined procedure (such as a constant-factor approximation algorithm) for its solution. Assuming the bin packing problem as the motivating example, we propose (and experiment with) exact single-level formulations for the problem where the leader affects the problem instance (modifying, e.g., the item weights and/or the bin capacity) in such a way that, by anticipating the procedure the follower would use to solve the resulting instance, the leader's objective function is maximized.
Keywords: bilevel programming; bin packing; mipping heuristics

1.19

A Support Planes Beam Search Algorithm for the Pallet Loading Problem

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We consider the Pallet Loading Problem (PLP), a variant of the three-dimensional bin packing problem which includes practical constraints related to the loading of boxes on pallets. In particular, we consider constraints on item rotations, static stability, load bearing and weight limit. We develop a new constructive heuristic for the PLP called Support Planes (SP), where a set of highly heterogeneous boxes is loaded on one or more pallets by solving a series of two-dimensional bin packing problems on planes created by placed boxes. We use SP as

a component for developing an efficient beam search algorithm for the PLP called the Support Planes Beam Search (SPBS). The proposed algorithm is evaluated on test instances from the literature, where it outperforms the current state-of-the-art algorithms both in terms of the quality of solutions and in in terms of time efficiency. After demonstrating the effectiveness of the developed algorithm, we test it on a series of large instances obtained from our industrial partner.
Keywords: 3d bin packing; pallet loading; beam search

1.20
Combinatorial Benders Decomposition for the Two-Dimensional Bin Packing Problem

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The two-dimensional bin packing problem calls for packing a set of rectangular items into a minimal set of larger rectangular bins. Items must be packed with their edges parallel to the borders of the bins, cannot be rotated, and cannot overlap among them. The problem is of interest because it models many real-world applications, including production, warehouse management, and transportation. It is, unfortunately, very difficult, and instances with just 40 items are unsolved to proven optimality, despite many attempts, since the 1990s. In this paper, we solve the problem with a combinatorial Benders decomposition that is based on a simple model in which the two-dimensional items and bins are just represented by their areas, and infeasible packings are imposed using exponentially many no-good cuts. The basic decomposition scheme is quite naive, but we enrich it with some preprocessing techniques, valid inequalities, lower bounding methods, and enhanced algorithms to produce the strongest possible cuts. The resulting algorithm behaved very well on the benchmark sets of instances, improving on average on previous algorithms from the literature and solving for the first time several open instances.
Keywords: two-dimensional bin packing problem; exact algorithm; Benders decomposition; combinatorial Benders cut

1.21
Parallel dynamic programming algorithms for large-scale two-dimensional guillotine cutting

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The unconstrained two-dimensional cutting (U2DC) problem involves cutting a rectangular sheet of material into an unlimited number of rectangular pieces of different sizes to maximize profit. In this work, we tackle the guillotine variant of the U2DC problem where only vertical and horizontal cuts that dissect a rectangle into two parts are allowed. Dynamic programming procedures are currently the state-of-the-art approach for solving the guillotine U2DC problem. These methods have been extensively proven to be effective and efficient, even for very large size problem instances. The interest in the guillotine U2DC problem and the relevance of these methods are further motivated by their relationship to the non-guillotine U2DC problem and the constrained version of the problem (C2DC), which imposes limits on the number of occurrences for each piece type. In particular, dynamic programming procedures provide the optimal solution for the guillotine U2DC problem, which also serves as a lower bound for the non-guillotine variant. Moreover, they yield a full matrix of suitable upper bounds for the C2DC problem for all rectangular sub-sheets. In this study, we have explored the potential benefits of two significant improvements to the state-of-the-art dynamic programming procedure for the U2DC problem. First, we present the results of a new implementation option for one of the three conditions that are used for anti-redundancy strategies on cut coordinates. Second, we propose a parallelization strategy that involves breaking the set of coordinate couples into a grid of rectangular blocks, which can be executed on a CPU/GPU platform. We investigated multiple parameter configurations, leading to a setting that enables well-balanced performance results on the set of instances used on a multi-core CPU platform. Moreover, we examined the impact of GPU features based on the CUDA^TM (Computer Unified Universal Architecture) model on the parallelization strategy, due to the SIMD (Single Instruction Multiple Data) type of parallel processing. Preliminary results have demonstrated that the proposed approaches outperform the best methods previously reported in the literature, leading to significantly improved performance.
Keywords: guillotine cutting; dynamic programming; parallel algorithms

1.22

Dealing with stochastic defects in 2D cutting stock problem applied to the Home Textile industry

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Dealing with end-product quality uncertainty in the cutting and packing problems (CP) is still a challenging research area. Only a few works approach the stochastic demand version of these problems. However, some production processes require several steps, and a quality check could be done between each of them. In this study, we tackle a new variant of the two-dimensional cutting stock problem, applied to the home textile industry, while considering the stochasticity of defects' appearance. This problem was first addressed without any defect appearance, under the name of Integrated Production Planning and Cutting Stock Problem (2D-IPPCSP), by Silva et al. (2015). This problem asks for the cutting of a set of piece types with the minimum amount of fabric rolls with predefined widths, where the generated cutting patterns are limited to two non-exact guillotine stages. The main objective function is to minimize the total costs, including production, stock, and cutting costs. In our stochastic variant, we consider multi-step production, multi-period, and stochastic defects. Indeed, in the home textile industry, several production steps are required before cutting the end-products. Each of these steps could lead to different types of defects, which means that only a part of the produced fabrics is usable and could be not enough to satisfy piece types' demand. To tackle this problem, we propose a stochastic programming model and a matheuristic, considering a finite set of scenarios based on defect probabilities. We analyzed the performance of the proposed methods through experiments using real-world instances.
Keywords: cutting stock problem; defect probabilities; stochastic programming; home textile industry

1.23

A novel reformulation for the single-sink fixed-charge transportation problem

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The single-sink fixed-charge transportation problem (SSFCTP) is a distribution problem in which a single customer must acquire a given number of units of the same item at the smallest possible cost. To do so, the customer has access to a set of supplier nodes with different capacities, fixed costs, and unit costs. This problem can also be formulated as a packing problem in which the supplier nodes represent one- dimensional containers. The SSFCTP is known to have many applications in the area of manufacturing and transportation as well as being an important subproblem of the fixed-charge transportation problem. However, previous algorithms from the literature did not fully leverage the structure of this problem, to the point of being surpassed by modern general-purpose mixed-integer programming solvers for large instances. In this work, we introduce a novel reformulation of the SSFCTP and study its theoretical properties. This reformulation leads to a range of new upper and lower bounds, dominance relations, linear relaxations, and filtering procedures. The resulting algorithm includes a heuristic phase and an exact phase, the main step of which is to solve a very small number of knapsack subproblems. Computational experiments carried out on existing and new types of instances indicate that our algorithm systematically reduces the resolution time of the state-of-the-art exact methods by several orders of magnitude.
Keywords: Mixed-integer programming; Fixed-charge transportation problem; Packing problem; Lagrangian relaxation; Knapsack problem

1.24

Deep Reinforcement Learning for Combinatorial Problems: A new approach for the 3DBPP container loading problem in logistics

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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.

Keywords: Combinatorial Optimization; Bin Packing Problem; Container Loading Problem; Logistics; Artificial Intelligence; Machine Learning; Reinforcement Learning

1.25
The k-Best Solutions of the 0-1 Knapsack Problem: Algorithms and Applications

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The problem of generating the k-best solutions to combinatorial optimization problems is of great interest and has been addressed by many authors since the early 1970s. We propose some new algorithms for computing the k-best solutions for the 0-1 Knapsack Problem (KP). These algorithms can be very useful, in particular, for developing effective column generation approaches. We first define a basic dynamic programming algorithm, and then we propose an enhanced version that improves the performance and allows for the generation of columns without specifying their number in advance, as well as the inclusion of additional constraints. We briefly introduce the classical dynamic programming procedure for the KP, and we describe a basic dynamic programming procedure for generating the k-best solutions. Then, we describe the well-known backward recursion for the KP that only computes the optimal solution, and we propose the new backward recursion to generate the k-best solutions. The latter algorithm generates only the necessary states and allocates memory dynamically as needed. These algorithms are also extended to solve the bounded and unbounded versions of the knapsack problem. To demonstrate the benefits of the proposed algorithms, we also describe an exact method for the bin packing problem and some of its variants based on a column generation procedure that generates multiple columns at a time. In the computational results, we analyze the performance of the proposed algorithms alone and when embedded in the exact method for the basic bin packing problem and some of its variants.

Keywords: Knapsack Problem; k-Best Solutions; Dynamic Programming; Column Generation

1.26
An efficient triangle mesh collision detection approach to three-dimensional irregular open dimension problems

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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.
Keywords: 3D irregular cutting and packing; open dimension problems; continuous rotation; triangle mesh representation; collision detection

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Irregular 3D multi-part production in additive manufacturing

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Nowadays, 3D printers are widely used by various industries for producing parts. There are several variations, but they mostly use an additive manufacturing process, where material is added to form a part, instead of removing material, as is the case on subtractive manufacturing. A subset of 3D printers use Fused Deposition Method (FDM) a type of additive manufacturing where a part is built by depositing melted filament material over a platform, layer-by-layer, until the complete part is built. Each layer needs to be drawn using a continuous path that fills its inside, similar to how a space-filling curve works for a 2D plane. Generating an appropriate path is a major challenge in this process due to the increased printing time and potential failure from stresses and deformations in the object. In many industries there is an advantage in being able to produce as many parts as possible in a single batch, so in situations where FDM is used, most multi-part printing follows two distinct strategies: Continuous (parts are printed simultaneously) or Sequential (parts are printed one after another). To determine de position of each part in the printing platform, the continuous approach only needs to consider the 2D non-overlapping constraints between pieces, since they are all built at the same time. This process, on failure, leads to the loss of the pieces that have not been fully printed. The alternative strategy, the sequential approach, minimizes these losses by discarding only the last printed piece. However, this approach needs to consider collision constraints of previously printed parts with the printing structure of the machine, which usually leads to the loss of a significant amount of printing space. Our contribution focuses on the sequential FDM 3D printing strategy, aiming to improve the usability of the printing space, by enabling a tighter placement of the pieces, while ensuring that collisions with the printing structure is avoided, increasing performance, efficiency and effectiveness.
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Keywords: 3D; Irregular

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Optimized packing non-spherical powder particles

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To obtain high-quality and durable parts by 3D printing, specific characteristics (porosity and proportion of various sizes particles) in the mixture used for printing or sintering must be assured. The high porosity of the finished products during 3D printing process leads to decreasing of their mechanical properties [6]. The packing density makes influence to the ability of the powder sintering. Optimization of the particle size distribution before sintering is important in the process of 3D printing when the microstructure is subject to certain requirements, such as a combination of fraction sizes and a microstructure of individual particles [1, 4]. Thus, a certain proportion between the particles characteristics must be maintained to reduce the porosity. To get a quality product (or 3D part), shapes of particles as well as their size distribution must be controlled to optimize the technological process of obtaining metal powders. This provides eliminating defects on the product surface. To predict these characteristics a mathematical model of optimized packing polyhedral objects (particles of titanium alloys) in a cuboidal container is presented and a solution algorithm is developed. The non-spherical particle packing algorithm is a modification of the spherical particle packing algorithm [22]. In practice millions polyhedral particles are used for filling a given volume to define the correspondence between the cuboid dimensions and the average Fere diameters of polyhedra. Taking into account the additive production, all filling operations should be performed in the upper layer of the container, which is referred to as an active layer. Placement of non-overlapping polyhedra is controlled in the active layer only, using the phi-function technique. The height of the active layer is iteratively updated to the current data. This way the simulation time can be reduced significantly. The proposed iterative algorithm simulates filling the cuboid by different shapes and sizes polyhedra. The active level parameters are updated in each iteration of the procedure. Numerical experiments demonstrate that the results obtained by the algorithm are very close to experimental findings. This justifies using numerical simulation instead of expensive experimentation.
Keywords: optimized packing; polyhedral powders; 3D printing

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How to include stability as a constraint in a MILP model for the Manufacturer's Pallet Loading Problem

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The Manufacturer39;s Pallet Loading Problem consists of efficiently packing a maximum number of identical rectangular boxes onto a single rectangular pallet. The problem arises in different logistic activities of storage and transportation of products packed in boxes and loaded on pallets and trucks, where efficient packing can lead to significant cost reduction and improved operational efficiency. Retail managers assume that some boxes will be damaged during transport and that pallet load stability is essential to ensure that they arrive at their destination undamaged. Interlocking in pallet loading refers to a strategy to arrange boxes on a pallet in such a way that they are securely held in place and prevent them from shifting during transportation. This helps reduce product damage and the risk of injury to employees when handling the pallet. In this work, a Mixed Integer Linear Programming model for Manufacturer39;s Pallet Loading Problem ensuring static stability through interlocking is proposed. Stability is considered in the relation of two successive pallet plans placed in layers, and four types of interlocking are considered in the mathematical model. Preliminary computational experiments with real instances were performed to evaluate the performance of the mathematical model. In addition, three stability metrics from the literature were also used to evaluate the loading plans defined by the mathematical model.
Keywords: Pallet loading; Stability metrics; Interlocking

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Extending the semi-discrete representation to 3D nesting problems

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A promising technique for handling the geometry in nesting problems is the semi-discrete representation. Both the items and the container are represented by a set of semi-discrete line segments. Until now the technique has only been applied to 2D nesting problems. The present work extends this concept to 3D nesting problems. We introduce a fast and scalable algorithm to solve nesting problems based on a semi-discrete representation of both the 3D non-convex pieces and the container. An efficient method to perform the 3D discretization is used. In addition, an efficient placement algorithm heavily relying on the semi-discrete data structure using the greedy deepest-left-bottom-fill strategy is proposed. An optimized ordering of the segment overlap tests is used. We benchmark the performance of the proposed algorithm against available results for some existing and new 3D irregular strip packing (open dimension) datasets. A comparable solution quality is obtained within a very short runtime, even when rotation of the pieces is considered. Moreover, it scales well when the number of pieces or the number of allowed rotations increases. The approach easily allows for parallelization, therefore a parallel version of the algorithm with dynamic load balancing is also tested. The performance of the parallel algorithm is evaluated on a multicore processor using different task sizes. Finally, we discuss the advantages and limitations of using the semi-discrete representation for 3D nesting problems.
Keywords: 3D nesting, irregular, semi-discrete representation

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Quasi-Packing spheres with ratio conditions

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We consider optimized packing different spheres into a given container under non-standard placement conditions. A sphere is considered placed in the container if at least a certain part of the sphere is in the container. Spheres are allowed to overlap each other according to predefined parameters. Ratio conditions are introduced to establish correspondence between the number of packed spheres of different radii. The packing aims to maximize the total number of packed spheres subject to ratio, partial overlapping and quasi-containment conditions. Two nonlinear optimization models are proposed for this ratio quasi-packing problem: mixed integer and continuous. A heuristic algorithm is developed that reduces the original problem to a sequence of continuous open dimension problems for quasi-packing scaled spheres. Computational results for finding global solutions for small instances and good feasible solutions for large instances are provided.
Keywords: sphere packing; ratio condition; partial overlapping; quasi-containment; optimization

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Methodology of solving packing problems using the Phi-Function technique

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A methodology for solving packing problems is presented. A general packing problem of arbitrary shaped objects is formulated as a mathematical programming model using the phi-function technique. Different variants of the optimization problem are considered depending on types of objective functions, shapes of objects/containers and special conditions motivated by applications, including dense packing, sparse packing, balanced packing. We discuss here mathematical models, solution strategies, methods/ algorithms applied for different classes of the packing problem illustrated with examples for 2D and 3D cases.
Keywords: Packing Problem; Phi-function Technique; Mathematical Modelling; Solution Strategy; Optimization; Methodology

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Cutting problems in the ornamental stone industry

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In the ornamental stone industry, the cutting of natural stone involves solving a two-dimensional cutting problem. In addition to the usual constraints of cutting and packing problems, the nature of the raw material and the cutting technology impose constraints not found in other industries. The component of the production process that we will address in this presentation is the cutting of stone panels. From a geometrical point of view, these panels are treated as two-dimensional objects, they have an irregular shape, they have defects and, most importantly, they are thick and very heavy compared to the most commonly treated raw materials in the literature. On the other hand, the cutting is done with a saw and therefore the patterns must be guillotineable. The thickness of the board, together with the cutting technology, produces an effect called overcut. An overcut is a cut in the raw material that extends beyond the edge of the piece to be cut. This effect imposes special, non-trivial constraints on cutting models and algorithms. In addition, the cutting machine has suction cup technology that allows it to lift and deflect partially cut sheets to avoid overcutting. However, this operation slows down the cutting process and consumes energy. This presentation will focus on the presentation and formal definition of these particular constraints and objectives, illustrated by videos, photographs and real cutting plans from a stone industry. This may motivate innovative research to address the specific characteristics of this cutting and packing application.
Keywords: Packing problem; ornamental stone

1.34

Incorporating Overcuts into a Mathematical Programming Model for 2D Rectangular Cutting Problems

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Overcut is a phenomenon that occurs in saw cutting processes and consists of a cut that extends beyond the boundary of the piece being cut. This effect can damage pieces placed on top of the cut unless there is sufficient separation between the pieces or alignment with another cut in the same direction. Some cutting machines have built-in suction cup technology that allows the half-cut parts to be mechanically removed from the cutting area so that they are not damaged by subsequent orthogonal cuts. However, this operation consumes two important resources, time and energy, and its cost must be balanced against the cost of the waste that would be created by the piece separation in the cutting plane. To the best of our knowledge, this constraint has never been explicitly treated in the literature and it is not trivial to address. Starting from the floating cuts model for two-dimensional guillotine and non-guillotine cutting problems, a mathematical programming model is presented and the computational results of its application are discussed.
Keywords: Overcuts; Mathematical Programming

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