18th ESICUP Meeting

Toledo, Spain, May 11-13, 2022

Organization

EURO THE ASSOCIATION OF EUROPEAN OPERATIONAL RESEARCH SOCIETIES

EWG ESICUP CUTTING AND PACKING

UCLM Universidad de Castilla-La Mancha

Welcome

Dear Friends,

Welcome to the 18th Meeting of ESICUP - The EURO Special Interest Group on Cutting and Packing. Since its formal recognition as a 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 organized across Europe with occasional meetings further afield including Tokyo (Japan), Buenos Aires (Argentina), Beijing (China), Mexico City (México) and our last meeting due to COVID was online and this 19th Meeting is now held in Toledo by the University of Castilla-La Mancha.

Once again, this meeting will serve as an instrument for the development of research and the dissemination of knowledge in our field. Twenty-two papers have been accepted for presentation, allowing for clear insights into the current state-of-the-art of cutting and packing and preparing the ground for fruitful discussions.

The University of Castilla-La Mancha is the flagship public academic institution in the autonomous community which gave it its name and in which is a leader in the creation and transmission of science, technology, innovation, culture and solidarity. UCLM is a modern and competitive institution, with almost 30,000 students, 2,270 lecturers and researchers and 1,059 administrative and service staff.

In its thirty years of operation, the UCLM has provided young people with access to higher education and has energized the life in the cities where its campuses have been established: Ciudad Real, Albacete, Cuenca and Toledo, as well as Almadén and Talavera de la Reina. The study programme at UCLM includes high quality standard proposals, adapted to the requirements of the employment world and which satisfy social demands in all areas. 44 Bachelor Degrees, 35 Official Master Courses and 18 PhD Programmes can be studied at UCLM.

Toledo was declared a World Heritage Site by UNESCO in 1986 for its extensive monumental and cultural heritage. Toledo is known as the "Imperial City" for having been the main venue of the court of Charles V, Holy Roman Emperor, and as the "City of the Three Cultures" for the cultural influences of Christians, Muslims and Jews reflected in its history. It was also the capital of the ancient Visigothic kingdom of Hispania, which followed the fall of the Roman Empire, and the location of historic events such as the Visigothic Councils of Toledo. Toledo has a long history in the production of bladed weapons, which are now popular souvenirs of the city

Thank you to the organising committee and the ESICUP co-ordinating committee for their time in making this meeting happen.

Julia Bennell, Francisco Parreño and Antonio Martinez

Julia Bennell
University of Leeds
Program Chair

Antonio Martinez
University of Southampton
Organizer

Fran Parreño
University of Castilla-la-Mancha
Organizer

Local Organizing Committee:

María Teresa Alonso Martínez
Iván Giménez Palacios
Francisco Parreño Torres

Information for Conference Participants

MEETING VENUE
The 18th ESICUP Meeting will be held at the Cobertizo San Pedro Mártir, Faculty of Legal and Social Sciences (UCLM), Toledo.

Address conference:
Cobertizo San Pedro Mártir, Faculty of Legal and Social Sciences (UCLM), Toledo

REGISTRATION
The registration desk will be located in the meeting venue where you will collect your name badge and registration pack for the event. Registration will be open from 8.30am to 9.00am, May 12, 2022 and during session breaks.

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).

NOTES ON PRESENTATION

- **Equipment**
  The conference room is equipped with an overhead projector and a laptop computer will be provided. We suggest that you bring your own computer and/or transparencies as a backup.
- **Length of Presentation**
  20 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 given at registration.

DIETARY, MOBILITY AND OTHER REQUIREMENTS
Please let the registration desk know if you have any additional special requirements.

GET-TOGETHER EVENING
May 11, 2022, from 19:00.

Note: Drinks and tapas included.

Taberna Skala

Cuesta Sal, 5, 45001, Toledo

CONFERENCE DINNER
May 12, 2022, from 20:30,

Hacienda del Cardenal

Paseo Recaredo, 24, 45004 Toledo

Three courses (starter + main + dessert), drinks included.

`https://www.haciendadelcardenal.com/`

GUIDED TOUR TOLEDO (ENGLISH)
May 13, 2022, from 16:00

Zocodover Square, s/n, 45001 Toledo

Person with orange umbrella

Program Overview

	Wednesday 11/05/2022	Thursday 12/05/2022	Friday 13/05/2022
9:00		Registration	Session 5 (4 talks)
9:30		Opening Session	
		Session 1 (4 talks)	
10:30			Coffee Break
11:00		Coffee Break	Session 6 (3 talks)
11:30		Session 2 (4 talks)	
12:00			Round table on "Perspectives on Cutting and Packing Problems"
13:00		Lunch Break	Lunch Break
15:00		Session 3 (4 talks)	
16:00			Guided Tour Toledo. Plaza de Zocodover
16:30		Coffee Break	
17:00		Session 4 (3 talks)	
19:00	Get Together. Taberna Skala		
20:30		Conference Dinner. Hacienda del Cardenal	

Scientific Program Schedule

Thursday

9:25 – 9:30

Opening Session

9:30 – 11:00

Session 1 *Chair: Célia Paquay*

1.1 – The pallet-loading vehicle routing problem with stability constraints
María Teresa Alonso, Antonio Martinez-Sykora†, Ramón Alvarez-Valdé‡s, Francisco Parreño**

1.2 – A mathematical formulation for a Capacitated Vehicle Routing Problem with pickups, Time Windows and 3D packing constraints
Emeline Leloup, Célia Paquay*, Thierry Pironet**

1.3 – Algorithms for the Pallet Building Problem with Contiguity and Visibility Constraints
Manuel Iori, Marco Locatelli†, Mayron C. O. Moreira‡, Tiago Silveira⋆*

1.4 – Loading and vehicle routing problem with cross-docking: a mathematical formulation
Célia Paquay, José F. Oliveira†*

11:30 – 13:00

Session 2 *Chair: Antonio Martinez-Sykora*

2.1 – Developing fast heuristics for irregular volume maximisation problems
Jonas Tollenaere, Tony Wauters**

2.2 – Adapting collision detection techniques from computer graphics for use in 2D irregular-shaped nesting problems
Jeroen Gardeyn, Tony Wauters**

2.3 – A fast deepest-left-bottom-fill algorithm to solve 3D nesting problems using a semi-discrete representation
Sahar Chehrazad, Dirk Roose*, Tony Wauters**

2.4 – Hybridising guided local search and penetration depth to solve the nesting problem: an approach towards zero-waste fashion design
Nesma ElShishtawy, Julia Bennell*, Pammi Sinha†*

15:00 – 16:30

Session 3 *Chair: Julia Bennell*

3.1 – OPTIMIZED PACKING JELLY ELLIPSES
T. Romanova, Yu. Stoyan*, A. Pankratov*, I. Litvinchev†, O. Kravchenko**

3.2 – Using leftovers to tackle uncertainty in the two-dimensional cutting stock problem
Douglas Nogueira do Nascimento, Adriana Cristina Cherri†, José Fernando Oliveira‡, Beatriz Brito Oliveira‡*

3.3 – Improving the long-term cutting plan on a furniture company: A Case Study
Marta Cabo, Edgar Possani*, Gustavo C. Martínez**

3.4 – SPARSE BALANCE LAYOUT OF ELLIPSOIDS
A. Pankratov, T. Romanova*, P.I. Stetsyuk†*

17:00 – 18:00

Session 4 *Chair: Antonio Galrão Ramos*

4.1 – 3D intelligent pallet loading algorithm for crossdocking automation
Pedro Rocha[*], António Ramos[†], Elsa Silva[*]

4.2 – Pick-up vehicle routing with packing constraints: a first mile problem under disruptions
Iván Giménez-Palacios[*], Francisco Parreño[*], Ramón Álvarez-Valdés[†], Célia Paquay[‡], Beatriz Brito Oliveira[⋆], Maria Antónia Carravilla[⋆], José Fernando Oliveira[⋆]

4.3 – Pallets delivery: two matheuristics for combined loading and routing
Elsa Silva[*], Ana Moura[†], António G. Ramos[‡]

Friday

9:00 – 10:30

Session 5 *Chair: Francisco Parreño Torres*

5.1 – A Combinatorial Flow-based Formulation for Temporal Bin Packing Problems
John Martinovic[*], Nico Strasdat[*], José Valério de Carvalho[†], Fabio Furini[‡]

5.2 – Generating hard 0-1 knapsack problem instances
Jorik Jooken[*], Pieter Leyman[†], Patrick De Causmaeckera[*]*

5.3 – Multi-container loading problems with multi-drop and split delivery conditions
Iván Gimenez[*], María Teresa Alonso[*], Ramón Álvarez-Valdés[†], Francisco Parreño[*]

5.4 – A Machine Learning Approach for 3D Load Feasibility prediction
Sarah de Wolf[*], Ruggiero Seccia[†], Leendert Kok[†] and Neil Yorke-Smith[*]

11:00 – 12:00

Session 6 *Chair: Elsa Silva*

6.1 – The cutting and packing problems under uncertainty: literature review, classification, applications, and trends
Khadija Hadj Salem[*], Elsa Silva[†], José Fernando Oliveira[†]

6.2 – On Problems of Packing and Covering Irregular Figures: Some Approaches to Formalization and Solution
Sergiy Yakovlev[*]

6.3 – The Floating-Cuts model: a general and flexible mixed-integer programming model for non-guillotine and guillotine rectangular cutting problems
Elsa Silva[*], José Fernando Oliveira[†], Tiago Silveira, Leandro Mundim[⋆], Maria Antónia Carravilla[†]

12:00 – 12:45

Round Table

– Perspectives on Cutting and Packing Problems
Ramón Álvarez-Valdés, Sarah de Wolf, José Fernando Oliveira, Célia Paquay and Elsa Silva

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12:45 – 13:00

Closing Session

Abstracts

1.1
The pallet-loading vehicle routing problem with stability constraints

María Teresa Alonso*, Antonio Martinez-Sykora†, Ramón Alvarez-Valdé‡s, Francisco Parreño*
* *University of Castilla-La Mancha, Spain.*
† *CORMSIS, University of Southampton, UK.*
‡ *University of Valencia, Spain.*

Our contribution addresses an integrated routing and loading problem in which the pallets ordered by a set of customers have to be delivered by a set of trucks so that the total distance travelled is minimized. The problem has two main distinctive features. On the one hand, when assigning pallets to trucks, strict packing constraints, concerning axle weight, stability, and sequential loading, must be considered. On the other hand, split delivery is allowed.
We have developed an integer linear model for the integrated problem, considering all routing and packing constraints. We have also designed a more efficient decomposition procedure in which some packing constraints are initially relaxed. Each time an integer solution is found in the search tree of the relaxed problem, it is checked to see whether it satisfies the remaining constraints and is therefore a feasible solution to the original problem. If it is not, a heuristic algorithm is first applied to rearrange the solution and, if it fails, an integer model is used, considering the packing problem for a single truck. If this also fails, a constraint is added to the relaxed problem to cut off the infeasible integer solution.
An extensive computational study shows how the integer linear model and the decomposition procedure work on a set of instances varying the number of customers, the number of pallets, and their weight distribution.
Keywords: Routing, packing, trucks, pallets, stability

1.2
A mathematical formulation for a Capacitated Vehicle Routing Problem with pickups, Time Windows and 3D packing constraints

Emeline Leloup*, Célia Paquay*, Thierry Pironet*
* *HEC - Liège, Management School of the University of Liège, Belgium*

Retailers are offering increasingly widespread e-commerce services and more and more parcels need to be transported. Thus, the retailers call on transportation service providers, for whom the packing of the boxes is crucial. In addition, they have to take into account the tour to be organised when collecting the boxes. Hence, the Capacitated Vehicle Routing Problem and the 3D Loading Problem and even its extension with time windows (3L-CVRPTW), which are NP-hard problems, should be tackled.
As the locations of collection and delivery of parcels may be geographically spread, the service carriers perform the collection on day 1 and delivery on day 2. Since unloading may thus be organized at the depot, the problem of collection and delivery are separated. In the literature, last-mile delivery has been extensively studied as opposed to the first movement of the goods within the supply chain, called first-mile pickup. However, box collection tends to be dynamic and the pickup process, in which the vehicle is initially empty, is much more able to react to disruptions occurring during the day.
In order to deal with real-life problems, we conduct a survey among eight Belgian transport service providers (SP) that helped to identify the main constraints and issues faced by the transportation service providers and the drivers during pickup trips. So, in this work, we consider the 3L-CVRPTW with (split) pickups and possible outsourcing of some customers' requests. The objective is to minimize the transportation and outsourcing costs while deciding (1) which vehicles will leave the depot and for those determine a route, a schedule, and successive valid packing plans, and (2) which customers to outsource.
We developed a mathematical formulation with routing, time, and packing constraints (namely, geometric, vertical stability, orientation, fragility, and multi-load) and we tested it on a set of small instances to determine its computational limitations. To the best of our knowledge, there are no instances available in the literature for this particular problem with customer locations, large time windows, and few boxes per customer. Thus, we combined benchmark instances from the literature for the VRP and the packing respectively. We generated 10 instances from 5 up to 20 customers respectively for small and large time windows.
With our formulation implemented in Java using IBM ILOG CPLEX 12.10 library, the Branch-and-Bound solver struggles to solve instances beyond 15 customers, each with around two boxes on average to be collected. The results enabled us to identify the maximum instance size that the B&B is able to solve. As the problem can be decomposed by nature, our next step is to develop an Insert-And-Fix heuristic to build a good initial solution.
Keywords: loading; routing; time windows; mathematical formulation

1.3

Algorithms for the Pallet Building Problem with Contiguity and Visibility Constraints

Manuel Iori*, Marco Locatelli†, Mayron C. O. Moreira‡, Tiago Silveira⋆

* *Department of Sciences and Methods for Engineering, University of Modena and Reggio Emilia, Reggio Emilia, Italy.*

† *Department of Engineering and Architecture, University of Parma, Parma, Italy.*

‡ *Department of Computer Science, Federal University of Lavras, Lavras, Brazil.*

⋆ *INESC TEC - Instituto de Engenharia de Sistemas e Computadores, Portugal, and Department of Engineering and Architecture, University of Parma, Parma, Italy.*

This work analyzes a specific problem from the "Cutting and Packing" field called *Pallet Building Problem* (PBP) with practical constraints. We address the case where the geometric shapes for both the items and containers are 3-dimensional boxes, being the containers identical one another, somewhat simplifying the problem, but not making it easy per se.

In the PBP, the aim is to pack a given set of items into layers and then build pallets by stacking layers one on top of the other, by minimizing the number of pallets used. We are considering a base set of constraints (items must fit entirely within the container, and items cannot overlap), and some non-trivial operational constraints that originate from a real-world automated application: in practice, items are grouped into families and must be packed into horizontal layers. To facilitate loading/unloading operations, items from the same family packed into the same layer should be contiguous with one another and at least one of them must be visible from the outside (Iori et al., 2020). In addition, we consider stackability and fill factor constraints.

The techniques we develop to solve the problem are heuristic, metaheuristic and matheuristic algorithms. Due to a complex set of constraints, we divide the PBP into two phases: (1) layer building; (2) pallet building. In simple terms, items are first grouped into horizontal layers, and then layers are stacked one over the other to form pallets. To solve this problem, we propose heuristics and matheuristics based on heuristics and integer linear models. The main heuristic we highlight is based on the adaptation of the Extreme Points heuristic (Crainic et al., 2008). In regards to the mathematical models, we propose them for solving specific parts of the problem. We then propose matheuristic algorithms by taking advantage of these efficient heuristics and the mathematical models. In addition to that, a significant improvement in the solution was noticed when adapting the PBP to the GRASP metaheuristic with reactive method (Alonso et al., 2014).

Extensive computational experiments were performed using real life instances from an Italian company in order to evaluate the algorithms effectiveness. We carried out a comprehensive analysis of the results using the proposed techniques, detailing their pros and cons. In a general analysis, the results confirm the power and flexibility of the algorithms and models.

Keywords: Pallet Building Problem, Practical Constraints, Constructive Heuristic, Reactive GRASP, Matheuristic, Real Life Instances.

1.4

Loading and vehicle routing problem with cross-docking: a mathematical formulation

Célia Paquay*, José F. Oliveira†

* *HEC-Management School of the University of Liege, Belgium.*

† *INESC-TEC, Faculdade de Engenharia, Universidade do Porto, Portugal*

A lot of pressure is put on logistic distribution system in order to satisfy highly impatient customers that expect, if not require, fast deliveries. The supply chain should be reactive on one hand, but also keep costs as low as possible. One way of achieving this goal is to make use of cross-docking, which is a technique that aims at reducing inventory and picking costs and shortening the shipping cycle.

Cross-docks differ from standard distribution centers by having no inventory, but allowing for goods consolidation between the suppliers and the customers. Cross-docking comes initially from industry, and it seems that Wal-Mart was one of the first retailers to implement this technique in the late 1980s. In more detail, the cross-docking system is composed of a network of locations, associated to suppliers and customers, as well as a (set of) cross-dock facility(ies). Inbound trucks collect goods from the suppliers, and bring them back to a cross-dock where they are unloaded at an input dock. Goods are then sorted and consolidated according to their destination. Next, the goods are loaded into outbound trucks at an output dock, and the trucks then deliver them to the customers.

While many aspects of the cross-docking may be optimized, we focus here on the routing and loading aspects. Over the past 15 years, many papers studied the Capacitated Vehicle Routing Problem with Cross-Docking (CVRP-CD). Basically, the VRP-CD can be seen as two interdependent VRPs (one for the suppliers and one for the customers) with temporal constraints associated to the goods arrival at the cross-dock. The key element of efficient cross-docking lies in the synchronization of the inbound trucks arriving at the facility and the outbound

trucks that leave to visit the customers. However, the loading aspect in the context of cross-docking has been barely studied, but never with the whole distribution network (inbound echelon, consolidation, and outbound echelon). This problem can be regarded as a 3-dimensional Loading CVRP-CD (3L-CVRP-CD).
This work proposes a mathematical formulation for the 3L-CVRP-CD, considering that the goods cannot be stocked in the cross-dock and that specific temporal constraints should be added to ensure the synchronization of the two echelons. The objective function is to minimize transportation costs. Regarding the packing constraints, we consider geometric and stability constraints, and in particular the multi-drop constraint and its pickup counterpart, the multi-load. This mathematical formulation was implemented and tested on toy instances, in order to validate the model and identify the instance size limit that a standard Branch-and-Bound algorithm (CPLEX) is able to solve.
Keywords: loading, vehicle routing, cross-docking, mathematical formulation

2.1 Developing fast heuristics for irregular volume maximisation problems

Jonas Tollenaere*, Tony Wauters*
* *KU Leuven, Belgium*

The objective of irregular volume maximisation problems is to find the biggest given 3D item(s) that can be extracted from a larger 3D object, where both the item(s) and the larger object can have irregular shapes. This objective requires determining the positions and rotations for the necessary items so they can be maximally scaled up without violating any constraints. Applications of this problem appear in select real-world contexts such as 3D-printing and gem cutting. These optimisation problems are challenging due to their three-dimensional and irregular nature, which results in large solution spaces and compute-intensive evaluations. Our goal is to find good solutions using methods that scale well with the complexity of objects, which are represented by triangular meshes. Previous research showed that working with exact and mathematical formulations soon requires an excessive amount of computation time as the number of triangles in the meshes increases (1). Given that we need to be able to handle real-world instances with meshes consisting of tens of thousands of triangles, (meta)heuristic approaches are better suited. This research focuses on techniques and algorithmic improvements we developed to accelerate heuristics that solve this problem. Here, we will only discuss instances where the volume of a single item must be maximised. While this may seem like a trivial optimisation problem, it is important to recognise its difficulty and usefulness as a building block for algorithms that solve extended variants of this problem. We define a baseline approach that uses established techniques like bounding volume hierarchies for collision detection and binary search to determine the maximum scale for an item with a given position and rotation. This sub-problem can then be iteratively resolved by (meta)heuristic algorithms in search for the optimal position and rotation. While this already proves to be a successful approach, we can introduce further improvements to significantly speed it up. By exploiting the geometric properties of this optimisation problem we can reduce both the number of times we have to solve the sub-problem as well as the time it takes to do so. Finally we compare our results against exact and matheuristic approaches on an expanded data set. (1) E. F. Silva, H. Çalık, W. Vancroonenburg, A. A. S. Leao, and T. Wauters, "Extracting maximal objects from three-dimensional solid materials," Computers & operations research, vol. 132, p. 105290, 2021.
Keywords: maximum volume extraction; cutting and packing; collision detection; heuristics; metaheuristics

2.2 Adapting collision detection techniques from computer graphics for use in 2D irregular-shaped nesting problems

Jeroen Gardeyn*, Tony Wauters*
* *KU Leuven, Belgium*

Nesting problems are widespread and occur in a range of different contexts, such as laser cutting, 3D printing and garment cutting. Determining whether a placement of an item is valid or not, which typically involves ensuring that no intersecting or overlapping occurs, is an essential part of all nesting algorithms. The efficiency and accuracy of these collision detection methods is therefore crucial. 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 (NFP) by computing Minkowski sums. However, these techniques are not without their limitations. Discretization quickly becomes memory intensive when targeting for high precision while NFP generators often lack robustness. Moreover, a unique NFP has to be computed for every possible rotation of every pair of polygons.

Another field where collision detection is very relevant is computer graphics. In particular video games, simulations and CAD. However, while the essence of the collision detection problem at hand is the same, the context differs greatly from nesting problems. Videogames, for example, generally have a more dynamic but also much parser environment when compared to 2D nesting. Techniques used in computer graphics generally consist of a combination of broad- and narrow-phase collision detection. The goal of the broad phase is to efficiently eliminate as much of the required computational work as possible. Afterwards, what remains can be solved with precise (and therefore more expensive) checks during the narrow phase.

The goal of this research is to investigate whether such a two-phased approach can be adapted into a robust, fast and accurate collision detection system for use in 2D nesting heuristics. In a first implementation, a datastructure based on quadtrees is used for the broad phase, combined with exact intersection and inclusion tests in the narrow phase. While this research is still in its early stages, initial experiments are already show promising results. The next steps are to develop a heuristic on top of this collision detection system which supports free rotation of items, irregular-shaped bins and holes.

Keywords: 2D nesting, irregular-shaped, collision detection, computer graphics

2.3 A fast deepest-left-bottom-fill algorithm to solve 3D nesting problems using a semi-discrete representation

Sahar Chehrazad*, Dirk Roose*, Tony Wauters*

* *Department of Computer Science, KULeuven, Belgium*

We present an efficient algorithm to solve the strip packing problem for 3D possibly non-convex polyhedral pieces, using a semi-discrete representation. The aim is to place the pieces without overlap in a cuboid container, while minimizing the x-dimension of the container. Both the pieces and the container are discretized in the x- and y-directions. A discretized piece is represented by a set of continuous line segments in the z-direction for each (x, y) grid point. We use a sweep-line algorithm that sorts the triangles in the input STL file of a polyhedron to efficiently discretize the pieces and the container. We apply extensions to the line segments of the polyhedron to ensure that non-overlapping placement of the line segments guarantees a non-overlapping placement of the polyhedron.

The proposed deepest-left-bottom-fill placement algorithm is an extension of the 2D bottom-left-fill algorithm using semi-discrete representation, that we developed earlier. Each semi-discretized y-z-plane of a 3D piece is placed in a semi-discretized y-z-plane of a 3D container using our proposed 2D bottom-left-fill algorithm. The placement can be performed very efficiently due to the use of appropriate data structures, simple arithmetic operations to detect and avoid overlap and an optimised ordering of the segment overlap tests.

The performance and the computational cost of the deepest-left-bottom-fill heuristic depends on the resolution (distance between the (x, y) grid points) and the number of rotation angles (in case rotation is allowed, testing the placement with each rotation angle can be done concurrently). Placement of 36 polyhedra ('Stoyan' data set), with the pieces ordered largest-first, when rotations are not considered, with resolution 0.1, results in a container depth of 43.1 and requires 189 ms on a single core of an Intel i9 CPU. As resolution gets coarse, the execution time decreases as the number of line segments representing a piece decreases and consequently the amount of computations required for checking whether a piece can be placed in a position decreases.

Since the operations for placement of the segments in each y-z-plane are independent, they can be executed concurrently on different cores of a multi-core processor. The parallel algorithm creates many tasks with sufficient grain size when using a sufficiently fine resolution, i.e., the distance between y-z-planes and between line segments in each plane. The execution time of the parallel deepest-left-bottom-fill algorithm with the same data set (rotations are not considered) and the same ordering of the pieces, with resolution 0.1, using 8 cores of an Intel i9 CPU is 34 ms (the obtained speedup is 5.5).

As the computing times are always in the order of milliseconds on an Intel i9 CPU, our algorithm can be considered as a high-performance building block for use in heuristics for optimal placement.

Keywords: 3D strip packing problem; deepest-left-bottom-fill algorithm; semi-discrete representation; sweep-line algorithm

2.4 Hybridising guided local search and penetration depth to solve the nesting problem: an approach towards zero-waste fashion design

Nesma ElShishtawy*, Julia Bennell*, Pammi Sinha†

* *University of Leeds Business School, United Kingdom.*

† *School of Design, University of Leeds, United Kingdom*

The fashion industry's impact on the environment is a significant global problem. One avenue for reducing the industry's global impact is by reducing the amount of waste generated in the cutting stage of fabric. The distinction between the role of fashion designer and marker maker means the "design" and "make" processes are linear, which allows for more waste on the cutting floor. Some designers are exploring the Zero Waste Design concept, which means designers consider the cutting of pattern pieces while designing garments. However, this approach has been criticised for not allowing designers to have aesthetic control over designs.
This research aims to transform the "design" and "make" processes from linear to circular and allow designers to have aesthetic control when designing a zero-waste or a minimal waste design. By developing an optimisation algorithm based on the overlap minimisation problem that aims to minimise the waste generated from the cutting stage of the fabric where irregular shapes need to be cut from a fabric roll, also known as the "Two Dimensional Irregular Strip Packing Problem". Through a collaboration with a designer, we aim at integrating the designer's design making process with the algorithm design to inspire the designer to make adjustments to the initial design through an iterative process until a satisfactory marker with minimal to zero waste is achieved. The research presents a hybrid algorithm that utilises guided local search and penetration depth to calculate the amount of overlap between a pair of polygons which is used to find the best position to translate a polygon in a specific direction. However, rather than only finding an optimal solution as the main objective, the algorithm is manipulated to allow us to offer different suggestions that can be used by the designer to change the original design in order to find a better layout utilisation.
Keywords: Cutting and packing; optimisation models; zero-waste fashion design

3.1
OPTIMIZED PACKING JELLY ELLIPSES

T. Romanova*, Yu. Stoyan*, A. Pankratov*, I. Litvinchev†, O. Kravchenko*
* *Institute for Mechanical Engineering Problems of the National Academy of Sciences of Ukraine, 2/10, Pozharsky St., Kharkov, 61046, Ukraine.*
† *Institute of Cybernetics of the NAS of Ukraine of National Academy of Sciences of Ukraine, Kyiv, Ukraine*

Non-standart problem of packing jelly ellipses under stretching and shrinking transformations in a minimal convex rectangle domain is presented. Metrical characteristics of ellipses can vary in a certain range subject to their individual areas' conservation. The limits for stretching (shrinking) ration of the half-axes of ellipses are assigned. Free translations and rotations of ellipses are allowable. The objective is minimizing the container's height. New mathematical tools to state analytically packing constraints are introduced based on the phi-function technique. The phi-functions are used for analytical presentation of placement conditions (non-intersection of jelly ellipses and containment (complete and relaxed) of jelly ellipses in a container). Packing jelly ellipses is stated as a nonconvex optimization problem. A multistart solution strategy is proposed. Two related problems are solved successively. First, an optimized circle packing problem is considered for the circles having the same area as individual ellipses. The layout obtained this way is used as a feasible starting point for packing jelly ellipses. Results of numerical experiment are discussed. Packing jelly ellipses is motivated by modeling porous media under pressure and arise in oil and gas extracting industry.
Keywords: Jelly ellipses, packing, quasi-phi-functions, mathematical modelling, optimization

3.2
Using leftovers to tackle uncertainty in the two-dimensional cutting stock problem

Douglas Nogueira do Nascimento*, Adriana Cristina Cherri†, José Fernando Oliveira‡, Beatriz Brito Oliveira‡
* *Departamento de Engenharia de Produção, Faculdade de Engenharia de Bauru, Universidade Estadual Paulista - UNESP - Brasil.*
† *Departamento de Matemática, Faculdade de Ciências, Universidade Estadual Paulista - UNESP - Brasil*
‡ *INESC TEC, Faculdade de Engenharia, Universidade do Porto - Portugal*

In real-world applications, a variation of the classical Cutting Stock Problem (CSP) has been considered as an effective strategy for further reducing waste. It consists of generating usable leftovers from the cutting process, which return to stock to meet future demands and are not considered waste. Considering two-dimensional problems, this variation is called Two-Dimensional Cutting Stock Problem with Usable Leftovers (2D-CSPUL). In a multiperiod perspective, the main difficulty of the 2D-CSPUL is planning the production of both demanded items and leftovers without knowing the future demand. Cutting patterns can be created to generate usable

leftovers with a high probability of use in future cutting processes, bringing several advantages for companies in terms of economic development, sustainability and social impacts. For the formulation of the 2D-CSPUL with uncertainty in demand, the problem can be divided into two stages. At the first stage, the decision variables are the frequencies of the cutting patterns used to solve a specific deterministic problem with a known demand. At the second stage, we assume that the uncertain demand can be approximated by a finite set of possible scenarios, each scenario with an associated probability of occurrence. Thus, the second-stage variables are the frequencies of the cutting patterns used to solve the problem associated with each possible scenario, and that will adjust the decisions made for the first-stage decision variables, optimizing the use of the leftovers generated at the first stage. This research contributes to the literature by proposing a matheuristic to solve the 2D-CSPUL with uncertainty in items demand. The matheuristic is divided into three steps: i) creating a set of cutting patterns is created for all types of plates in stock, with and without usable leftovers; ii) generating scenarios for items demand using an evolution method based on a BRKGA (Biased Random-Key Genetic Algorithm) framework proposed in the literature; and iii) solving a stochastic mathematical model that uses the cutting patterns from i) and the scenarios from ii). The stochastic model was solved by an exact solver and through a new proposed method adapted from the L-shaped method. The efficiency of the proposed matheuristic was verified through computational tests with instances from the literature. This research has been supported by the Fundação de Amparo a Pesquisa do Estado de São Paulo - FAPESP [2019/25041-8], [2018/16600-0] and [2016/01860-1]. This work is also partially funded by the ERDF – European Regional Development Fund through the Operational Programme for Competitiveness and Internationalisation - COMPETE 2020 Programme and by National Funds through the Portuguese funding agency, FCT - Fundação para a Ciência e a Tecnologia, I.P., within project POCI-01-0145-FEDER-029609.
Keywords: Two-dimensional cutting stock problem, usable leftovers, uncertainty in demand, stochastic problem, matheuristic

3.3
Improving the long-term cutting plan on a furniture company: A Case Study

Marta Cabo*, Edgar Possani*, Gustavo C. Martínez*
* *ITAM – México*

In this talk we will present a two-dimensional cutting problem to optimize the use of raw material in a furniture company. Since the material used to produce pieces of furniture comes from a natural source, the plywood sheets may present defects that affect the total area that can be used in a single sheet. The heuristic presented in this research deals with these defects and present the best way to handle them. It also considers the use of the plywood sheets for the long-term planning of the company. When the defects arise randomly the decisions on how to pack a certain set of pieces may impact on the number of stock sheets needed from one packing pattern to the next, even if the set of pieces is the same. Companies usually buy their stock to last for several weeks, and the cutting of pieces is made constantly, thus we need to ensure that the available stock will be sufficient until the next shipment arrives. Plywood is also considered a perishable item, as without the ideal conditions for storage it is affected by temperature and humidity changes. Thus, small companies with limited storage capacity can only use plywood up to a certain time after ordering it. It is also important to consider that inventory costs are high, so buying sufficient stock sheet to satisfy even the worst-case scenario may not be feasible due to the high cost of holding inventory, and the possibility that the raw material may become useless after a certain period of time. The order in which the pieces are cut as well as the order in which the plywood is used affects the number of plywood sheets used in a planning period. We present a dynamic programming model that takes all these variables into consideration and minimizes the expected costs of the orders. We will present a comparison between different policies to determine the savings companies may incur when implementing a more efficient use of the raw material and compare it with the cost of implementing such policies. We also compare the results obtained with the proposed model with the fixed ordering policy most companies used nowadays.
Keywords: Inventory Control, Dynamic Program, Cutting with Defects

3.4
SPARSE BALANCE LAYOUT OF ELLIPSOIDS

A. Pankratov*, T. Romanova*, P.I. Stetsyuk†
**Institute for Mechanical Engineering Problems of the National Academy of Sciences of Ukraine, 2/10, Pozharsky St., Kharkov, 61046, Ukraine.*
† *Nuevo Leon State University (UANL), Monterrey, Av. Universidad s/n, Col. Ciudad Universitaria, San Nicolas de los Garza, Nuevo Leon, CP 66455, Mexico.*

The paper considers the optimization problem of generating elleptical voids in three dimensional domains. The problem is reduced to the problem of arranging ellipsoids in a convex container with prohibited zones, taking into account restrictions on "sparseness" of the ellipsoids and balancing conditions (a location of the gravity center of the system). A mathematical model in the form of a nonlinear programming problem is provided. Algorithms of searching for feasible and locally-optimal solutions using NLP-solver and r-algorithm are proposed. The results of numerical experiments are given.
Keywords: sparse layout, ellipsoids, phi-function, nonlinear programming, r-algorithm.

4.1

3D intelligent pallet loading algorithm for crossdocking automation

Pedro Rocha*, António Ramos†, Elsa Silva*
* *INESC TEC, Porto, Portugal.*
† *INESC TEC, School of Engineering, Polytechnic of Porto, Porto, Portugal.*

Storage space constraints and increased storage cost tend to favor smaller sized shops compared to larger ones, making the process of allocating consumer goods to it very challenging, especially in an environment with an increasing demand for customized consumer goods. This creates an incentive to improve consumer demand forecasting and supply-chain responsiveness to specific consumer demands, in order to reduce the quantity of in-transit inventory and its average lead-time. Real-world transportation is constantly influenced by multiple variables, leading to an increased lead- time variability, which disrupts the planned scheduling by anticipating or delaying the reception of items. This increases storage space requirements at the cross-docking warehouse until orders are ready to be fulfilled, while requiring flexibility in the scheduling and sequencing of products to be palletized and expedited. The flow of products is one of the aspects that can be significantly improved in the cross-docking system by implementing an automated mixed-palletizing system, focused on efficiency and safety, since most logistic centers lack a sufficient degree of automatization for selection, picking, packaging and dispatching processes. An automated cross docking mixed-palletizing system would reduce the storage requirements while also increasing throughput, by quickly adapting to changes in scheduling due to delays in reception. The materialization of this concept implies overcoming significant technical and scientific challenges. Since the moment of arrival of items is not known in advance (only the scheduled time), the items must be palletized as they arrive, by building the 3D palletization pattern in real-time, and using an automated process to build it, such as a robot that produces the most compact, stable and safe pallet. In this process, one component that is a significant challenge is the online generation of the 3D palletization patterns. The offline variant of the problem is known in the literature as the Distributer's Pallet Loading Problem (DPLP). In this work, we consider a heuristic solution based on genetic algorithms for the online DPLP, while also considering loading sequence viability, pallet stability and balancing, operational safety during loading and unloading, and mitigation of damages during transportation. The pallet pattern is also adjusted for the handling capabilities of the palletizing robot. While this work has shown successful in addressing these challenges, there is still a lot that remains to be done, in terms of palletization quality and efficiency, particularly the computational cost associated with their generation.
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Keywords: Distributor's Pallet loading; Logistics; heuristics

4.2

Pick-up vehicle routing with packing constraints: a first mile problem under disruptions

Iván Giménez-Palacios*, Francisco Parreño*, Ramón Álvarez-Valdés†, Célia Paquay‡, Beatriz Brito Oliveira⋆, Maria Antónia Carravilla⋆, José Fernando Oliveira⋆
* *University of Castilla-La Mancha, Spain.*
† *University of Valencia, Spain.*
‡ *University of Liege, Belgium.*
⋆ *University of Porto, Portugal*

First-mile logistics tackles the movement of products from retailers to a warehouse or distribution centre. This first step towards the end customer has been pushed by large e-commerce platforms forming extensive networks of partners and is critical for fast deliveries. First-mile pickup requires efficient methods different from those developed for last-mile delivery, among other reasons due to the complexity of cargo features and volume – increasing the relevance of advanced packing methods. More importantly, the problem is essentially dynamic and

the pickup process, in which the vehicle is initially empty, is much more flexible to react to disruptions arising when the vehicles are en route. We model the static first-mile pickup problem as a vehicle routing problem for a heterogeneous fleet, with time windows and three-dimensional packing constraints. Moreover, we propose an approach to tackle the dynamic problem, in which the routes can be modified to accommodate disruptions – new customers' demands and modified requests of known customers that are arriving while the initially established routes are being covered. We propose three reactive strategies for addressing the disruptions depending on the number of vehicles available, and study their results on a newly generated benchmark for dynamic problems. The results allow quantifying the impact of disruptions depending on the strategy used and can help the logistics companies to define their own strategy, considering the characteristics of their customers and products and the available fleet.
Keywords: first-mile logistics, disruption, vehicle routing, packing

4.3

Pallets delivery: two matheuristics for combined loading and routing

Elsa Silva*, Ana Moura†, António G. Ramos‡
* *INESC TEC, Porto, Portugal.*
† *Govcopp and University of Aveiro, Aveiro, Portugal.*
‡ *INESC TEC and School of Engineering, Polytechnic of Porto, Porto, Portugal*

The implementation of new regulatory and technical requirements for the distribution of vehicle axle weights in road freight transport, places a new set of constraints on the vehicle routing. Until now, axle weight distribution in the determination of the load plan in the freight transport units have been neglected in determining the routing of vehicles. The compliance with the axle weight constraints is of great importance for road freight transport companies since non-compliance with the axle weight distribution legislation translates into heavy fines.
This work aims to provide a tool capable of generating cargo loading plans and routing sequences for a palletized cargo distribution problem. The problem addressed integrates the capacitated vehicle routing problem with time windows and the two-dimensional loading problem with balance constraints.
Two integrative solution approaches are proposed, one giving greater importance to the routing and the other prioritizing the loading. Moreover, a new MILP model for the 2D pallet loading problem with balance constraints, that take advantage of the standard dimension of pallets, is proposed. Extensive computational experiments were performed with a set of well-known literature benchmark instances, extended to incorporate additional features. The computational results show the effectiveness of the proposed approaches.
Keywords: Vehicle Routing Problem; Vehicle Loading; Load Balance; Matheuristic

5.1

A Combinatorial Flow-based Formulation for Temporal Bin Packing Problems

John Martinovic*, Nico Strasdat*, José Valério de Carvalho†, Fabio Furini‡
* *Institute of Numerical Mathematics, Technische Universitaet Dresden, Dresden, Germany.*
† *Departamento de Produção e Sistemas/Centro ALGORITMI, Universidade do Minho, Braga, Portugal.*
‡ *Department of Computer, Control and Management Engineering \Antonio Ruberti, Sapienza University of Rome, Rome, Italy*

We consider two neighboring generalizations of the classical bin packing problem: the temporal bin packing problem (TBPP) and the temporal bin packing problem with fire-ups (TBPP-FU). In both cases, the task is to arrange a set of given jobs, characterized by a resource consumption and an activity window, on homogeneous servers of limited capacity. To keep the operational costs but also the energy consumption low, TBPP is concerned with minimizing the number of servers in use, whereas TBPP-FU additionally takes into account the switch-on processes required for their operation. In both cases, challenging integer optimization problems are obtained, which can differ significantly from each other despite the seemingly only marginal variation of the problems. In the literature, a branch-and-price method enriched with many pre- processing steps (for the TBPP) and compact formulations (for the TBPP-FU), benefiting from numerous reduction methods, have emerged as, currently, the most promising solution methods. In this paper, we introduce, in a sense, a unified solution approach for both problems based on graph theory. Any scientific contributions in this direction failed so far because of the exponential size of the associated networks. The approach we present in this article does not change the theoretical exponentiality itself, but it can make it controllable by clever construction of the resulting graphs. In particular, this leads to the fact that for the first time all classical benchmark instances (and even larger ones) for the two

problems can be solved - in times that significantly improve those of the previous approaches.

Keywords: Cutting and Packing - Temporal Bin Packing - Fire Ups - Interval Scheduling - Combinatorial Arcflow

5.2

Generating hard 0-1 knapsack problem instances

Jorik Jooken*, Pieter Leyman*†, Patrick De Causmaeckera*

* *CODeS, Department of Computer Science, KU Leuven Kulak.*

† *Department of Engineering Management, University of Antwerp*

In this abstract, we will discuss one of our recent publications in European Journal of Operational Research in which we propose a new class of hard problem instances for the 0-1 knapsack problem. The goal of the 0-1 knapsack problem is to select a subset of items (from a given set of items that each have a certain profit and weight) such that the sum of the profits is maximized and the sum of the weights does not exceed a given capacity. The 0-1 knapsack problem is a fundamental NP-hard optimization problem and has received a lot of attention for several decades, which resulted in extremely powerful algorithms that are able to solve most (large) problem instances from the literature in several seconds. This is remarkable, because the 0-1 knapsack problem is NP-hard and this motivated researchers to investigate where the hard problem instances for the 0-1 knapsack problem are located. Amongst others, it led to Pisinger's seminal paper entitled 'Where are the hard knapsack problems?' and a more recent paper by Smith-Miles et al. in which this question is revisited using the Instance Space Analysis methodology.

In our current work, we further build upon this line of research concerned with hard problem instances for the 0-1 knapsack problem and we propose noisy multi-group exponential problem instances. For these problem instances, there are multiple groups of items with exponentially decreasing profits and weights between different groups. These profits and weights are slightly perturbed with random uniform noise to introduce diversity amongst the different items.

In this work, we give theoretical arguments that help us understand why noisy multi-group exponential problem instances are hard to solve to optimality. The developed theorems give further insight into the structure of the solution landscape associated with these problem instances. We also empirically show that the proposed problem instances are hard. A large set consisting of 3240 noisy multi-group exponential problem instances was systematically generated and then solved on a supercomputer using approximately 810 CPU-hours. The analysis of these results reveals that our problem instances take several orders of magnitude longer to solve than the previously hardest problem instances, despite being much smaller. Finally, we visually show the location of our problem instances in the problem instance space by projecting the problem instances to a two-dimensional space using the Instance Space Analysis methodology. This visualisation shows that our problem instances fill an important previously unfilled gap of the problem instance space where the hard problem instances are located.

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Keywords: combinatorial optimization, 0-1 knapsack problem, problem instance hardness

5.3

Multi-container loading problems with multi-drop and split delivery conditions

Iván Gimenez*, María Teresa Alonso*, Ramón Álvarez-Valdés†, Francisco Parreño*

* *University of Castilla-La Mancha, Spain.*

† *University of Valencia, Spain*

We consider a multi-container loading problem in which each customer orders a set of pallets of different weights and the objective is to meet all orders with the minimum number of trucks required to deliver the orders of a set of customers when hard packing constraints, on the one hand, and split delivery, on the other, have to be taken into account. These two types of conditions are becoming increasingly common in recent studies combining routing and packing. Strict constraints regarding stability, multidrop, and axle weight limits must be respected for each truck at each stop along the route. When assigning pallets to trucks, split delivery is allowed, even if each customer's order fits on a single truck.

We first developed an integer linear model including all packing constraints. As the model is not fast enough in large instances, we have developed a decomposition procedure that works as a matheuristic, combining heuristics and an integer model to produce the optimal solution. Our extensive computational study shows that the new procedure is able to obtain the optimal number of trucks for all the instances tested. In addition, our results also show the influence of the weight distribution on the solution process. Heavy loads make the packing constraints harder to satisfy and the whole problem much more difficult to solve.

The results also enable us to identify the situations in which the possibility of split delivery has a strong impact on the number of trucks required.
Keywords: multi-container loading, split delivery, stability, integer models

5.4

A Machine Learning Approach for 3D Load Feasibility prediction

Sarah de Wolf*, Ruggiero Seccia†, Leendert Kok†, Neil Yorke-Smith*
* *Faculty of Electrical Engineering, Mathematics and Computer Science, Delft University of Technology, Delft, The Netherlands.*
† *ORTEC, Math Innovation Team, Zoetermeer, The Netherlands*

Vehicle routing problems (VRP) and 3D Container Loading Problems (3D-CLP) have been studied for decades. However, the combination of the two deserves more attention than in the literature to date. When solving VRP problems, computed routes must be checked for feasibility. Among the feasibility checks to perform, we need to guarantee that the load plan is feasible, namely that all the assigned products fit inside the truck. This involves solving a 3D-CLP. Since the check of load plan feasibility is performed frequently, a short computational time is important. Hence, the load plan feasibility check is usually performed using approximation methods. Having rapid and reliable load plan feasibility estimations is crucial to reduce computational times when solving the VRP problem. However, if these estimations are conservative, the obtained routes are inefficient routes; if the estimations are opportunistic, the resulting load plans can turn out to be infeasible. In this ongoing work, we explore to what extent supervised Machine Learning (ML) methods can be used to rapidly yet accurately classify whether load plans will be feasible or not. Indeed, several advantages are derived from introducing ML-based feasibility estimation methods. In particular, while computational time of standard heuristic methods depend on the number of items in each load plan, ML approaches are size-independent, meaning that their computational time is not affected by the size of the plan to load. Moreover, ML approaches have the advantage of not requiring human-based definitions of specific heuristics for each customer but, by exploiting hidden patterns inside the available data, can automatically derive complex models. Thus, ML predictions can be exploited in VRP algorithms to improve efficiency and computational times.
Several ML methods are considered and benchmarked on synthetic data and real data from a major company in the beverage sector. Extended experiments in different settings are performed, to check the effectiveness of ML in providing reliable load plan estimations and to extract insights on how load plan characteristics affect load feasibility. Preliminary results suggest the effectiveness of applying ML models, with random forest models reaching an accuracy above 93% on all different experiments considered.
Keywords: Vehicle Routing Problem; Load Feasibility; Machine Learning; Classification

6.1

The cutting and packing problems under uncertainty: literature review, classification, applications, and trends

Khadija Hadj Salem*, Elsa Silva†, José Fernando Oliveira†
* *Mines Saint-Etienne, Univ Clermont Auvergne, CNRS, UMR 6158 LIMOS, Institut Henri Fayol, F-42023 Saint-Etienne France.*
† *INESC TEC, Porto, Portugal.*

The cutting and packing problems (C&P) is an active research area that has been addressed by Operations Research (OR) community for more than 60 years. The first empirical studies go back to the 1939s, and the first modeling approaches back to the 1965s , using column generation techniques. Over the years, C&P research has seen a wide range of problems with applications in many manufacturing industries requiring cutting materials such as textiles, glass, metal, ceramics, and leather. Most well-known studies have dealt with different mathematical modeling approaches to tackle the C&P problems considering deterministic parameters. However, just a few works approach the stochastic version of the C&P problems. The earliest we found is due to Sculli (1981). Despite the recent progress in this research area, no work has yet systematized published research with a clear focus on uncertainty management. As a result, there is neither any up-to-date structured literature nor a unique model approach and no benchmark sets are available. In this survey paper, we provide a literature review on C&P problems under uncertainty (stochastic demands, defects, etc.) and propose a classification framework of the most mathematical models used to deal with uncertainty. We also present suggestions and future lines of research that point to the most promising open questions in this area.
Keywords: C&P problems; Cutting Stock Problem; Bin Packing Problem; Uncertainty; Defects;

Stochastic Demands; Integer Linear Programming; Stochastic Programming; Robust Optimization; Simulation Optimization; Scenarios Generation; Monte Carlo Simulation.

6.2
On Problems of Packing and Covering Irregular Figures: Some Approaches to Formalization and Solution

Sergiy Yakovlev*

* *Technical University of Lodz, Poland; National Aerospace University, Kharkiv Aviation Institute, Ukraine*

The article describes an approach to solving packing and covering optimization problems for irregular objects (figures). To formalize the conditions for pairwise non-intersection of geometric objects (in the packing problem) and the conditions for covering a domain by a set of geometric objects (in the covering problem), a special class of omega-functions is proposed. Algorithmic approaches to the calculation of such functions are described using modern computational geometry packages, in particular the Shapely Python. To solve optimization problems of packing and covering, metaheuristic methods are used, in particular, evolutionary algorithms.
Keywords: packing and covering problems, irregular figure, formalizing, optimization, Shapely Python

6.3
The Floating-Cuts model: a general and flexible mixed-integer programming model for non-guillotine and guillotine rectangular cutting problems

Elsa Silva*, José Fernando Oliveira†, Tiago Silveira‡, Leandro Mundim⋆, Maria Antónia Carravilla†

* *INESC TEC - Instituto de Engenharia de Sistemas e Computadores, Portugal.*

† *INESC TEC, Faculdade de Engenharia, Universidade do Porto, Portugal.*

‡ *INESC TEC, Departamento f Engineering and Architecture, University of Parma, Italy.*

⋆ *Optimized Decision Making (ODM), São Carlos, Brazil*

Cutting and packing problems are challenging combinatorial optimization problems that have many relevant industrial applications and arise whenever a raw material has to be cut into smaller parts while minimizing waste, or products have to be packed, minimizing the empty space. Thus, the optimal solution to these problems has a positive economic and environmental impact. In many practical applications, both the raw material and the cut parts have a rectangular shape, and cutting plans are generated for one raw material rectangle (also known as plate) at a time. This is known in the literature as the (two-dimensional) rectangular cutting problem. Many variants of this problem may arise, led by cutting technology constraints, raw-material characteristics, and different planning goals, the most relevant of which are the guillotine cuts. The absence of this imposition makes the problem harder to solve to optimality. Based on the Floating-Cuts paradigm, a general and flexible mixed-integer programming model for the general rectangular cutting problem is proposed. To the best of our knowledge, it is the first mixed integer linear programming model in the literature for both non-guillotine and guillotine problems. The basic idea of this model is a tree search where branching occurs by successive firstorder non-guillotine-type cuts. The exact position of the cuts is not fixed, but instead remains floating until a concrete small rectangle (also known as item) is assigned to a child node. This model does not include decision variables either for the position coordinates of the items or for the coordinates of the cuts. Under this framework, it was possible to address various different variants of the problem. Extensive computational experiments were run to evaluate the model's performance considering 16 different problem variants, and to compare it with the state-of-the-art formulations of each variant. The results confirm the power of this flexible model, as it outperforms the state- ofthe-art approaches for some variants while remaining very competitive for the others. But, even more importantly, this is a new way of looking at these problems which may trigger even better approaches, with the consequent economic and environmental benefits.
Keywords: cutting; non-guillotine and guillotine cutting and packing problems; mixed-integer linear programming model; tree search

List of Participants

Alonso Martínez, Maria Teresa
Universidad de Castilla-La Mancha
mariateresa.alonso@uclm.es
Spain

Alvarez-Valdes, Ramon
Universidad de Valencia
ramon.alvarez@uv.es
Spain

Bennell, Julia
University of Leeds
j.bennell@leeds.ac.uk
UK

Cabo Nodar, Marta
ITAM
marta.cabo@itam.mx
México

Carravilla, Maria Antónia
Universidade do Porto
mac@fe.up.pt
Portugal

Chehrazad, Sahar
KULeuven
sahar.chehrazad@kuleuven.be
Belgium

Clautiaux, François
Université de Bordeaux
francois.clautiaux@math.u-bordeaux.fr
France

de Wolf, Sarah
ORTEC
sarah.dewolf@ortec.com
The Netherlands

Elshishtawy, Nesma
University of Leeds
Bn17nre@leeds.ac.uk
UK

Evers, Justine
University of Liège
jevers@uliege.be
Belgium

Galrão Ramos, António
Polytechnic of Porto
agr@isep.ipp.pt
Portugal

Gardeyn, Jeroen
KULeuven
jeroen.gardeyn@kuleuven.be
Belgium

Giménez Palacios, Iván
Universidad de Valencia
ivan.gimenez@uv.es
Spain

Hadj Salem, Khadija
Polytechnic of Porto
hadj.salem@inesctec.pt
Portugal

Jooken, Jorik
KULeuven
jorikjooken@gmail.com
Belgium

Lastra Díaz, Juan José
LECTRA
j.lastra@lectra.com
Spain

Leloup, Emeline
University of Liège
emeline.leloup@uliege.be
Belgium

Martinez Sykora, Antonio
University of Southampton
a.martinez-sykora@soton.ac.uk
UK

Oliveira, José Fernando
Universidade do Porto
jfo@fe.up.pt
Portugal

Pankratov, Alexander
National Academy of Sciences of Ukraine
pankratov2001@yahoo.com
Ukraine

Paquay, Célia
University of Liège
cpaquay@uliege.be
Belgium

Parreño Torres, Francisco
Universidad de Castilla-La Mancha
Francisco.Parreno@uclm.es
Spain

Pironet, Thierry
University of Liège
thierry.pironet@uliege.be
Belgium

Poza Lobo, Juan Carlos
Lantek
i.torresdebilbao@lantek.com
Spain

Rocha, Pedro
Polytechnic of Porto
pfr@isep.ipp.pt
Portugal

Romanova, Tetyana
National Academy of Sciences of Ukraine
tarom27@yahoo.com
Ukraine

Roose, Dirk
KULeuven
Dirk.Roose@kuleuven.be
Belgium

Schyns, Michaël
University of Liège
M.Schyns@uliege.be
Belgium

Sergiy, Yakovlev
Technical University of Lodz
svsyak7@gmail.com
Poland

Silva, Elsa
Polytechnic of Porto
elsa.m.silva@inesctec.pt
Portugal

Silveira, Tiago
Polytechnic of Porto
tiago.silveira@inesctec.pt
Portugal

Tollenaere, Jonas
KULeuven
jonas.tollenaere@kuleuven.be
Belgium

Valério de Carvalho, José
Universidade do Minho
vc@dps.uminho.pt
Portugal

Wäscher, Gerhard

gerdwaescher@icloud.com
Germany