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# Welcome

Dear Friends,

Welcome to the 17th 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) and our last meeting in Mexico City.

2020 saw the first year we did not hold a meeting since the group's launch. While we planned to hold the meeting in Toledo in April 2020, it became clear that this was simply not viable. With the global pandemic still profoundly affecting our lives and restricting our travel and social contact, we decided to hold the 2021 meeting online. Toledo will have to wait another year.

Once again, this meeting will serve as an instrument for the development of research and the dissemination of knowledge in our field. Thirty 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. Moreover, we are delighted to have four tutorials from Manuel Iori (Università degli Studi di Modena e Reggio Emilia), Victor Milenkovic (University of Miami), Tom Cherrett (University of Southampton) and Patrick De Causmaecker (Katholieke Universiteit Leuven).

The meeting will be held via zoom, while the technical organisation and support for the conference provided by the team at the Universidad de Castilla-La Mancha and the University of Southampton, with the organising committee led by Francisco Parreño and Antonio Martinez.

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

# Information for Conference Participants

The 17th ESICUP meeting will be held online using ZOOM. Sessions will take place over the full week of 22nd to 26th March from 14.00 to 17.30 CET (13.00 to 16.30 UTC).

The conference is a single stream. If you have registered to the conference you will receive an email with the ZOOM link and password to join to the conference. We will be using the same link for all the ten sessions and four tutorials. When you join the conference you will enter a waiting room. We ask that you clearly display your name and affiliation so we can identify you prior to letting you into the conference.

Note, you do not need a ZOOM license to access this link. Both presenters and participants use the same link. We kindly request that presenters and chairs join the sessions five minutes early to check their presentations are able to be displayed.

Presenters should plan for 15-18 mins presentation leaving a few minutes for questions.

During session, we request all participants keep their mics on mute. At the end of the presentation, participants can raise their hands and the session chair will invite you to unmute and ask your questions

The chat function will be available where you can ask the speaker a question that they can respond to after the presentation.

We ask that all discussion both through questions and in chat is constructive and respectful.

If you are struggling to connect please contact esicup@gmail.com

# Program Overview

Note that times shown in the table correspond with GMT/UTC times.

| | Monday 22/03/2021 | Tuesday 23/03/2021 | Wednesday 24/03/2021 | Thursday 25/03/2021 | Friday 26/03/2021 |
|---|---|---|---|---|---|
| 13:00–14:00 | Guest Speaker: **Manuel Iori** (session 1) | 3 talks (session 4) | 3 talks (session 7) | Guest Speaker: **Tom Cherrett** (session 10) | Guest Speaker: **Patrick De Causmaecker** (session 13) |
| 14:00–14:15 | BREAK | BREAK | BREAK | BREAK | BREAK |
| 14:15–15:15 | 3 talks (session 2) | 3 talks (session 5) | 3 talks (session 8) | 3 talks (session 11) | 3 talks (session 14) |
| 15:15–15:30 | BREAK | BREAK | BREAK | BREAK | Closing remarks |
| 15:30–16:30 | 3 talks (session 3) | Guest Speaker: **Viktor Milenkovic** (session 6) | 3 talks (session 9) | 3 talks (session 12) | |

# Tutorials

## Tutorial 1 **Chair:** Julia Bennell

**Manuel Iori, University of Modena and Reggio Emilia (Italy)**

**Title:** Combinatorial Benders decompositions for two-dimensional packing problems

**Abstract:** Two-dimensional (2D) packing problems require to pack a set of rectangular items into one or more rectangular bins, without overlapping and by optimizing a given objective function. They are among the most difficult problems in combinatorial optimization, and several instances with just 20 items remain unsolved to proven optimality despite decades of research.

In this talk, we will show how combinatorial Benders decompositions, also known as Logic-based Benders decompositions, can be used to solve 2D packing problems. Such decomposition consists in dividing the original problem into a master problem and a sub-problem. In the case of our 2D packing methods, the master problem takes into account the x-coordinates of the items, whereas the sub-problem the y-coordinates.

We will present computational results that we obtained on 2D strip packing and bin packing problems. We will also present a number of generic and effective techniques that can be used to speed up the basic decomposition scheme. These include preprocessing algorithms, reductions of the search space, lifted cuts, as well as lower and upper bounding techniques.

**Manuel Iori** is associate professor in operations research at the Department of Sciences and Methods of Engineering (DISMI) of the University of Modena and Reggio Emilia (UNIMORE), Italy, where he also acts as responsible of the international activities.

His research activity concerns the development of mathematical models and algorithms for operations research, combinatorial optimization and logistics, with applications in vehicle routing, bin packing, knapsack, traveling salesman, parallel machine scheduling, multi-dimensional cutting and packing, optimal layout and shortest paths.

He published more than 80 papers in peer-reviewed journals, including Operations Research and Mathematical Programming. He has been in the program committee of the conferences EURO, Odysseus, ICCL, GECCO, LAGOS and Matheuristics. He is a collaborating member of CIRRELT, in Canada, and he spent research periods as visiting professor in Universities in Brazil, Canada, Chile, France, Great Britain and Spain.

## Tutorial 2 **Chair:** Ramon Alvarez-Valdes

**Victor Milenkovic**

**Title:** ACP: A Library for Robust Geometric Computation

**Abstract:** The ACP (Adaptive Controlled Perturbation) library provides support for exact and efficient geometric computation. The library supports the definition of geometric objects and the evaluation of predicates on objects. Objects are defined as parametric functions of input parameters and of antecedent objects. Predicates compute the sign (-1, 0, 1) of algebraic expressions in the parameters of their arguments. This talk will explain how to use ACP and review some of the ways we have used it: exact packing of three polyhedra into a box using translation, exact path planning for a three degree of freedom robot with rotation, approximate path planning for a four degree of freedom drone, and exact arrangements of algebraic surfaces.

**Victor Milenkovic** is a Professor of Computer Science in the College of Arts and Sciences of the University of Miami. He joined the faculty of the Department of Mathematics and Computer Science in 1994. In 2000, he founded the Department of Computer Science, and he served as chair from 2000-2003. From 1988-2004, he was a faculty member of the Division of Applied Sciences of Harvard University.

Victor's research interests lie in computational geometry, numerical analysis, mathematical programming, nesting and layout, path planning, and physically based animation. He has developed and continues to develop techniques for "robust geometry": addressing numerical issues in the implementation of algorithms of computation geometry. He has applied these techniques and those of mathematical programming to the problems of finding locally and globally optimal layouts of parts for clothing and other manufacture. Similarly, these techniques have led to algorithms for animating crowded scenes with more than 1000 rigid bodies.

In 1991, Victor received the NSF Presidential Young Investigator Award. He has received research funding from the National Science Foundation, the Sloan Foundation, and the National Textile Center, the Textile/Clothing Technology Corporation, and the University of Miami Edward Arnold Confluent Media Laboratory. Royalty income from Microdynamics and Gerber Garment Technologies for software developed by Victor and his students at Harvard exceeds $300,000, and he continues a relationship with Gerber. Other layout software was put to use in the micro-electronics industry.

Victor received his A.B. degree, summa cum laude in Mathematics, from Harvard and his Ph.D. in Computer Science from Carnegie Mellon University.

## Tutorial 3 **Chair:** Antonio Martinez

**Tom Cherrett**

**Title:** The packing and optimisation challenges of switching to portering/cycle couriering for last-mile B2C parcel delivery

**Abstract:** With the increasing imposition of low emission zones alongside policies to favour walking, cycling and public transport in our inner cities, the challenge of delivering consumer goods to ever exacting time schedules is becoming more complex. This has been further exacerbated by the Covid-19 pandemic which has effected an irreversible switch to home-delivery and away from traditional high street retail. As a result, logistics providers are embracing new methods of home delivery involving sustainable modes of transport to mitigate the negative impacts of congestion, increase efficiency and meet the delivery windows demanded by consignees. The Freight Traffic Control 2050 project (www.ftc2050.com) developed the 'portering' concept working with Gnewt Cargo and Fedex which saw trials of walking porters in areas of London. This has now been further developed by Ford who are currently working with Hermes to use porters in SE11 (https://media.ford.com/content/fordmedia/feu/en/news/2021/02/11/smart-use-of-vans-and-pedestrian-couriers-could-make-online-shop.html). This presentation will describe the challenges associated with designing and operating secondary portering rounds using 200L wheeled bags as part of an existing B2C parcel delivery service in inner London.

**Tom Cherrett** Tom is a Professor in Logistics and Transport Management within the Transportation Research Group. He teaches transport planning, freight and passenger systems and construction management to Masters and Undergraduate students. His research interests cover: i) Core goods distribution (things that we buy) and how retail logistics can be made more efficient within and between our urban areas but particularly over the last mile. ii) The use of smartphone technology in logistics to enable customers and employees to better share and use data iii) Remote monitoring technology working with optimisation techniques to more effectively manage the collection of waste and recyclables in urban areas. He has over 130 journal and conference papers published and is a Chartered Member of the Institute of Logistics and Transport.

## Tutorial 4 **Chair:** José Fernando Oliveira

**Patrick De Causmaecker**

**Title:** Data science meets optimization, is one to help the other?

**Abstract:** We review the historical link between the domains of data science and optimization. The potential benefits of this interaction and the difficulties linked to its implementation are discussed. As an example, the domain of automated algorithm creation, selection and configuration is reviewed in more detail. Finally, based on concrete examples, it is demonstrated how techniques in both research domains can be set to use to improve the results on both sides.

**Patrick De Causmaecker** is a Professor at the Department of Computer Science, University of Leuven, Leuven, Belgium. He is programme director of POC WIF KULAK - Faculty of Science of University of Leuven and head of the Subdivision Combinatorial Optimisation and Decision Support.

His research interests cover: Mathematical Modelling,Discrete Optimisation,Meta and Hyper Heuristics, Algorithm Engineering, Algorithms and Constraints, Algorithms and Machine Learning, Algorithms and Knowledge Representation and Applications in Logistics: Production, Health care, Engineering, Physics, E-Learning, Bio-informatics.

# Scientific Program Schedule

Note that times shown in the table correspond with GMT/UTC times.

## Monday 22nd

**13:00 – 14:00**

**Session 1** *Chair:* Julia Bennell

– Combinatorial Benders decompositions for two-dimensional packing problems
*Manuel Iori*

**14:15 – 15:15**

**Session 2** *Chair:* Rosephine Georgina Rakotonirainy

2.1 – Automating the planning of container loading for Atlas Copco: Coping with real-life stacking and stability constraints
*Jonas Olsson*, Torbjörn Larsson* and Nils-Hassan Quttineh**

2.2 – Towards a framework for predicting strip packing algorithmic performance
*Rosephine Georgina Rakotonirainy**

2.3 – An optimization approach for a complex real-life container loading problem
*Mikele Gajda*, Alessio Trivella†, Renata Mansini* and David Pisinger‡*

**15:30 – 16:30**

**Session 3** *Chair:* Maria Teresa Alonso

3.1 – Loading pallets into trucks – An integer linear programming approach
*António Ramos*, Elsa Silva†, José F. Oliveira‡*

3.2 – The effect of Complete Shipment in Container Loading Problem
*Iván Giménez-Palacios*, Maria Teresa Alonso*, Ramón Álvarez-Valdés†, Francisco Parreño**

3.3 – Solving the pallet-loading vehicle routing problem with stability constraints
*María Teresa Alonso*, Ramón Alvarez-Valdés†, Francisco Parreño*, Antonio Martinez-Sykora‡*

## Tuesday 23rd

**13:00 – 14:00**

**Session 4** *Chair:* Tony Wauters

4.1 – Consideration of Axle Weight Constraints in 2L- and 3L-CVRP
*Corinna Krebs*, Jan Fabian Ehmke**

4.2 – Reflect, an enhanced pseudo-polynomial formulation for the bin packing and other related problems
*Maxence Delorme* and Manuel Iori†*

4.3 – Two-dimensional cutting stock problem with usable leftovers: an exact and non-exact approach
*Douglas Nogueira do Nascimento*, Adriana Cristina Cherri†, José Fernando Oliveira‡*

**14:15 – 15:15**

**Session 5** *Chair:* François Clautiaux

5.1 – VND-based algorithm on Packing and scheduling for lockage through Three Gorges and Gezhouba Dams
*Xiaopan Zhang*, Julia Bennell†*

5.2 – A heuristics based on dynamic programming for the two-dimensional cutting problem
*Assis, N. S. * and Rangel, S. †*

5.3 – Improved dynamic programming algorithms for large-scale two-dimensional guillotine cutting
*MASONE Adriano*[*†], *RUSSO Mauro*[‡†], *SFORZA Antonio*[*†], *STERLE Claudio* [*†]

**15:30 – 16:30**

**Session 6** *Chair:* Ramon Alvarez-Valdes

6.1 – ACP: A Library for Robust Geometric Computation
*Victor Milenkovic*

## Wednesday 24th

**13:00 – 14:00**

**Session 7** *Chair:* Fran Parreno

7.1 – Solving a large cutting problem in the glass manufacturing industry
*Ramon Alvarez-Valdes*[*], *Francisco Parreño*[†], *Maria Teresa Alonso*[†]

7.2 – Heuristic tree search for geometrical packing problems
*Florian Fontan*[*], *Luc Libralesso*[*]

7.3 – Mathematical models for a cutting problem in the glass manufacturing industry
*Francisco Parreño*[*], *Ramón Alvarez-Valdes*[†]

**14:15 – 15:15**

**Session 8** *Chair:* Elsa Silva

8.1 – An efficient parallel algorithm to solve nesting problems using a semi-discrete representation
*Sahar Chehrazad*[*],*Dirk Roose*[*], *Tony Wauters*[*]

8.2 – A general mixed integer programming model for rectangular guillotine cutting problems
*Elsa Silva*[*], *José F. Oliveira*[†], *Leandro Mundim*[‡], *Maria Antónia Carravilla*[†]

8.3 – The constrained two-dimensional guillotine placement problem: the bottom-up models
*Mateus Martin*[*], *Reinaldo Morabito*[*], *Pedro Munari*[*]

**15:30 – 16:30**

**Session 9** *Chair:* Michele Monaci

9.1 – A matheuristic algorithm for the container stowage planning problem with practical constraints
*Consuelo Parrenño*[*], *Hatice C¸ alık*[†], *Ramó Álvarez-Valdés*[*], *Rubén Ruiz*[‡]

9.2 – The Integrated Production Planning and Cutting Stock Problem in Home-Textile Industry: ILP formulations and an $\epsilon-$Constraint approach
*Khadija Hadj Salem*[*], *Elsa Silva*[*], *José.F. Oliveira*[*], *Maria.A. Carravilla*[*]

9.3 – Computational and theoretical analysis of the Multi-Period Cutting Stock Problem with setups on cutting patterns
*Eduardo Machado Silva*[*], *Gislaine Mara Melega*[†], *Kerem Akartunali*[‡] *and Silvio Alexandre de Araujo*[*]

## Thursday 25th

**13:00 – 14:00**

**Session 10** *Chair:* Toni Martinez-Sykora

– The packing and optimisation challenges of switching to portering/cycle couriering for last-mile B2C parcel delivery
*Tom Cherrett*

**14:15 – 15:15**

**Session 11** *Chair:* Silvio De Araujo

*11.1* – The machining torch movement for the rectangular sheet metal plasma cutting process.
*Alvaro Neuenfeldt Júnior*, David Disconzi*, Gabriel Stieler*, Matheus Francescatto**

*11.2* – The meet-in-the-middle principle for cutting and packing problems
*Jean-François Côté*, Manuel Iori†*

*11.3* – A Lookahead Matheuristic for the Unweighed Variable-Sized Two-dimensional Bin Packing Problem
*Sergey Polyakovskiy*, Rym M'Hallah†*

**15:30 – 16:30**

**Session 12** *Chair:* Tatiana Romanova

*12.1* – Optimized packing ellipses and its application for Additive Manufacturing
*T. Romanova*, Y. Stoyan*, A. Pankratov*,, I. Litvinchev‡, J.A.Bennell†*

*12.2* – A ray-casting approach for collision detection in 3D irregular cutting and packing problems
*Jonas Tollenaere*, Wim Vancroonenburg*, Tony Wauters**

*12.3* – Cutting Stock Problem with due dates and variable processing times
*Felipe Kesrouani Lemos*, Adriana Cristina Cheri*, Silvio Alexandre de Araujo**

## Friday 26th

**13:00 – 14:00**

**Session 13** *Chair:* Jose Fernando Oliveira

– Data science meets optimization, is one to help the other?
*Patrick De Causmaecker*

**14:15 – 15:15**

**Session 14** *Chair:* Célia Paquay

*14.1* – A Goal-Driven Ruin and Recreate Heuristic for the 2D Variable-Sized Bin Packing Problem with Guillotine
*Jeroen Gardeyn*, Tony Wauters**

*14.2* – A Branch-and-Price Algorithm for the Multiple Knapsack Problem
*Olivier Lalonde*, Jean-Franąois Côté†, Bernard Gendron**

*14.3* – The 3D bin packing problem with weight distribution constraints
*Pauline Pochte*, Mario Schwerdt*, Henriette Koch**

# Abstracts

1

## Automating the planning of container loading for Atlas Copco: Coping with real-life stacking and stability constraints

Jonas Olsson*, Torbjörn Larsson* and Nils-Hassan Quttineh*
* *Linköping University, Sweden*

The Atlas Copco† distribution center in Allen, TX, supplies spare parts and consumables to mining and construction companies across the world. For some customers, packages are shipped in sea containers. Planning how to load the containers is difficult due to several factors: heterogeneity of the packages with respect to size, weight, stackability, positioning and orientation; the set of packages differs vastly between shipments; it is crucial to avoid cargo damage. Load plan quality is ultimately judged by shipping operators.
This container loading problem is thus rich with respect to practical considerations. These are posed by the operators and include cargo and container stability as well as stacking and positioning constraints. To avoid cargo damage, the stacking restrictions are modeled in detail. For solving the problem, we developed a two-level metaheuristic approach and implemented it in a decision support system. The upper level is a genetic algorithm which tunes the objective function for a lower level greedy-type constructive placement heuristic, to optimize the quality of the load plan obtained.
The decision support system shows load plans on the forklift laptops and has been used for over two years. Management has recognized benefits including reduction of labour usage, lead time, and cargo damage risk.
† This project for Atlas Copco took place in 2015 and 2016. The company has since been split into Atlas Copco AB and Epiroc AB as of 2018, and the packing and container loading activities described in this paper are now part of the latter company.
Full article available here: https://doi.org/10.1016/j.ejor.2019.07.057
**Keywords**: Logistics; Packing; Decision support systems; Metaheuristics

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## Towards a framework for predicting strip packing algorithmic performance

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

The two-dimensional strip packing problem consists of packing a set of rectangular items into a single object of fixed width in a non-overlapping manner, with the objective of minimising its height. This problem has a wide range of applications, and is typically encountered in the wood, glass and paper industries.
Discovering the conditions under which strip packing algorithms succeed or fail with respect to a set of test instances is crucial for algorithm selection. Large scale computational studies involving the assessment of the relative performance of a variety of strip packing algorithms across a collection of diverse classes of benchmark instances provide the resources to derive such conditions.
In this presentation, the task of objective strip packing algorithm performance assessment is discussed. A framework for understanding the relationship between critical features of problem instances and the performance of algorithms is presented. The aims are to demonstrate the use of this framework to model the aforementioned relationships, and to show how the characteristics of the test instances can be used to predict algorithm performance on previously unseen instances with high accuracy.
**Keywords**: strip packing problem, performance prediction, comparative analysis

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## An optimization approach for a complex real-life container loading problem

Mikele Gajda*, Alessio Trivella†, Renata Mansini* and David Pisinger‡
* *University of Brescia.*
† *ETH Zurich.*
‡ *Technical University of Denmark*

In this work, we consider a real-world packing problem motivated by Italmondo, an Italian transportation and logistics worldwide Group active since 1953, through its IT & Digital Consulting Company Supernova. In its day-to-day B2B operation, Italmondo delivers goods via trucks from a central warehouse to its customers located in different European countries. For each shipment, the company has to decide which rectangular shaped items to

select and how to load them into the truck. The goal is loading the cargo safely inside the truck while maximizing the cargo taxability, which is defined for each item as a function of weight and volume.
In the literature, this problem is known as the Container Loading Problem (CLP). The basic version of CLP deals with optimizing the arrangement of cargo inside a container so that the value of transported cargo (taxability in our case) is maximal. In our application, the cargo should also respect regulation and safety constraints including a maximum weight limit; load balancing across the truck axles; fragile items placed on the top; static stability; dangerous items close to the unloading side of the truck. Moreover, since a truck may serve multiple customers, boxes for a customer should be unloaded without moving other boxes that are being shipped to destinations further down the line.
Currently, the loading decisions are taken manually by the warehouse personnel resulting in solutions which are not feasible and/or presenting low taxability. Thus, approaches based on optimization have the potential to improve with respect to this status significantly. Although some of the constraints have been considered in the CLP literature, our CLP is particularly challenging because: (i) the unloading constraints, considered in combination with the other constraints, are new and hard to handle, and (ii) balancing the cargo while maximizing its value are two conflicting objectives.
Our problem is NP-hard and difficult to formulate as a mixed-integer linear program; hence we tackle it using a heuristic approach. Specifically, we propose a greedy randomized constructive heuristic that: (i) sorts the items based on criteria like taxability, volume, and unloading order, (ii) perturbs the item list using a randomization function, and (iii) builds the packing by allocating items iteratively in specific support points inside the container. Repeating this procedure results in different packings due to our randomization. Since the resulting algorithm is very fast, we can run it many times and choose the best non-dominated solutions.
Testing our algorithm on real data sets, we obtained solutions in which cargo is well-balanced, all constraints are respected, and the taxability improves substantially compared to the company's results. Further work includes modifying the item list by exploiting ideas from genetic algorithms instead of using a randomization function.
**Keywords**: Container loading problem; real-life constraints; load balancing; industry collaboration.

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## Loading pallets into trucks – An integer linear programming approach

António Ramos*, Elsa Silva†, José F. Oliveira‡
* *INESC TEC and School of Engineering, Polytechnic of Porto, Porto, Portugal.*
† *INESC TEC, Porto, Portugal.*
‡ *INESC TEC and Faculty of Engineering, University of Porto, Porto, Portugal*

The problem addressed in this work involves the loading of heavy preloaded pallets into vehicles. It is a variant of the multi-container loading problem, frequently found in distribution operations.
The problem considers orientation constraints, non-overlapping constraints, a weight limit of the vehicle and dynamic stability constraints. The problem is solved using an integer linear programming model, where each pallet is an item, and each vehicle is a container. The goal is to minimize the number of vehicles and the number of pallets in the last used vehicle.
The proposed model is benchmarked against existing formulations to similar problem variants, using a set of instances generated by a new proposed instances generator. The computational experiments show that the proposed model can obtain the optimal solution in most instances.
**Keywords**: container loading problem, weight limit, dynamic stability

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## The effect of Complete Shipment in Container Loading Problem

Iván Giménez-Palacios*, Maria Teresa Alonso*, Ramón Álvarez-Valdés†, Francisco Parreño*
* *University of Castilla-La Mancha.*
† *University of Valencia.*

Efficient logistic planning has an impact on transport companies, which can make greater profits, and on the environment, by reducing pollution. One of the most common problems is Container Loading Problem, which involves loading boxes into containers or trucks so that empty space is minimized. In practical situations, besides the basic geometric constraints, there some other physical and logistic constraints to be considered, and some of them have hardly been studied. This is the case of Complete Shipment. This restriction models a real situation in which orders for the same client are formed by several boxes, and therefore when we are going to load them in the container, either we load them all or we do not load any of them. In this work, we study with four different heuristic strategies the effect of the Complete Shipment constraint on the Container Loading Problem. Our computational results show that when using an appropriate strategy, the impact of these constraints is quite small.

**Keywords**: Container Loading, Logistic Constraints, Complete Shipment

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## Solving the pallet-loading vehicle routing problem with stability constraints

María Teresa Alonso*, Ramón Alvarez-Valdés†, Francisco Parreño*, Antonio Martinez-Sykora‡
* *University of Castilla-La Mancha.*
† *University of Valencia.*
‡ *University of Southampton.*

We will present our mathematical model and results for a distribution problem that includes both the packing and routing of customer orders. The model needs to assign pallets to trucks, decide the position of the pallets on the trucks so that a customer's pallets are together and finally the route the trucks will take.
We study a problem in logistics that integrates routing and packing aspects. A distribution company supplies different products to many customers and has to decide how to load the products into trucks and determine the route of each truck. The products are packed into pallets and then pallets are loaded into the trucks, locating all the pallets of each customer together, to facilitate the unloading process.
The demand of a customer can exceed the truck capacity and, therefore, we allow solutions that split the delivery of a given customer across several trucks. Each truck can carry a maximum weight and there is also a weight limit on each axle. In addition, the load inside each truck must be stable when the truck is moving to avoid displacement during the journey. All these routing and packing constraints are included into an integer linear model where the objective is to minimize the total travel distance.
We present an extensive computational study, varying the number and locations of the customers and the number and weight of the demanded pallets, which shows the performance and the limits of the proposed model. Since the model becomes intractable with even small instances, we propose a decomposition algorithm in which some of the packing constraints are relaxed in the model and then considered by a heuristic packing algorithm. If the heuristic fails, an auxiliary model is then used to ensure the optimality of the solution obtained.
**Keywords**: Routing, packing, trucks, pallets, stability

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## Consideration of Axle Weight Constraints in 2L- and 3L-CVRP

Corinna Krebs*, Jan Fabian Ehmke*
* *Otto-von-Guericke University, Magdeburg, Germany*

The overloading of axles of trucks is a constant problem despite latest technical advances in the measuring of axle weights. Overloading axles not only leads to increased erosion on the road surface, but also to an increased braking distance and more serious accidents due to higher impact energy. Therefore, the load on axles should be considered during the planning phase and thus before loading the truck in order to prevent overloading. Hereby, a detailed 2D or 3D planning of the vehicle loading space is required. Suitable for the 2D and 3D Container Loading Problem, we model the axle weight constraint for trucks with and without trailers based on the Science of Statics. We include the axle weight constraint into the combined vehicle routing and container loading problem ("2L-CVRP" and "3L-CVRP"). A hybrid approach is used where an outer Adaptive Large Neighbourhood Search tackles the routing problem and an inner Deepest-Bottom-Left-Fill algorithm solves the packing problem for the route. Moreover, to ensure feasibility, we show that the axle weight constraint must be checked after each placement of an item. Our tests of several instance sets from literature indicate that the additional consideration of the axle weight constraint mostly leads only to slight deterioration of the objective values.
**Keywords**: Axle Weight Constraint, Vehicle Routing Problem, Container Loading Problem

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## Reflect, an enhanced pseudo-polynomial formulation for the bin packing and other related problems

Maxence Delorme* and Manuel Iori†
*The University of Edinburgh, University of Modena and Reggio Emilia*

In this work, we study mathematical models for the famous Bin Packing Problem (BPP) in which one wants to pack a set of weighted items into the minimum number of identical capacitated bins. BPP models could be clustered into three groups: (i) those with polynomial number of variables, (ii) those with pseudo-polynomial number of

variables (polynomial in both the number of items and the bin capacity), and (iii) those with exponential number of variables.
Models with polynomial number of variables (such as the textbook model) can be solved directly through Integer Linear Programming (ILP) solvers, but usually obtain bad performances due to their weak continuous relaxation. Pseudo-polynomial models (such as the arc-flow model) can also be solved directly through ILP solvers and obtain state-of-the-art performances when the capacity of the bin is reasonable. Models with exponential number of variables (such as the set covering model) cannot be solved directly with ILP solvers and need to embedded in a branch-and-price algorithm.
Due to the advantageous trade-off between the simplicity of their implementation and their good performances, many researchers have studied pseudo-polynomial models for the BPP in the recent years, with the common objective to reduce the number of variables/constraints they involve.
After a brief review of the pseudo-polynomial formulations that were proposed in the literature recently (arc-flow, arc-flow with graph compression, and meet-in-the-middle), we introduce reflect, a new formulation that uses just half of the bin capacity to model an instance and needs significantly fewer constraints and variables than the classical models. We show that reflect can be adapted to many related packing problems such as the variable-sized BPP, the BPP with item fragmentation, the multiple knapsack problem, and the skiving stock problem. For each problem, we carry out extensive computational experiments and we show that reflect is solved faster on average by ILP solvers than the other mathematical models.
**Keywords**: bin packing, pseudo-polynomial formulations, exact algorithms

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## Two-dimensional cutting stock problem with usable leftovers: an exact and non-exact approach

Douglas Nogueira do Nascimento*, Adriana Cristina Cherri†, José Fernando Oliveira‡
* *Departamento de Engenharia de Produção, FEB, UNESP, Bauru, SP, Brasil.*
† *Departamento de Matemática, FC, UNESP, Bauru SP, Brasil.*
‡ *Departamento de Engenharia e Gestão Industrial, FEUP, Universidade do Porto, Portugal.*

The Cutting Stock Problem (CSP) is a well-known problem in the literature, with practical application in multiple industries. In the two-dimensional cutting stock problems, a set of standard rectangular objects available in stock must be cut to produce smaller rectangular items. The cutting process must be planned in order to meet a known demand while optimizing an objective function. In real-world applications, a variation of the CSP has been considered as an effective strategy for further reducing waste. It consists of generating usable leftovers from the cutting process, which are not considered waste and return to stock to meet future demands. This variation of the CSP is called Cutting Stock Problem with Usable Leftovers (CSPUL). We use 2D-CSPUL to refer to the two-dimensional cutting stock problem with usable leftovers. In the 2D-CSPUL, 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 sustainability, social impacts, and economic development. This research contributes to the literature by proposing a non-linear mathematical model, and its linearization, to represent the 2D-CSPUL. These models simultaneously build cutting patterns and determine their frequencies. For the construction of these cutting patterns, the rectangular objects available in stock are divided into horizontal strips,. Furthermore, two items can be combined to create new types of items called "macro-items". Each cutting pattern can generate just one usable leftover obtained from a horizontal guillotine cut, ensuring that it has the same width as the cut object and height within a predefined range. Although we consider leftovers in stock, only standard objects can generate new usable leftovers. The non-linear and linear mathematical models were solved using commercial solvers. Being these cutting problems NP-hard, when using exact solution methods only small and medium-sized instances are solved to optimality. To solve larger instances, a heuristic procedure that decomposes the original problem into smaller problems is proposed, reducing the computational effort to obtain satisfactory integer solutions. The efficiency of both models and the heuristic procedure was verified through computational tests with instances randomly generated and instances from the literature. This research has been supported by the Fundação de Amparo à Pesquisa do Estado de São Paulo - FAPESP (2018/16600-0), (2018/07240-0) 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
**Keywords**: Two-dimensional cutting stock problem, usable leftovers, mathematical model, heuristic procedure.

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## VND-based algorithm on Packing and scheduling for lockage through Three Gorges and Gezhouba Dams

Xiaopan Zhang*, Julia Bennell†

* *Resources and Environmental Engineering School, Wuhan University of Technology, Wuhan, China;* † *Business School, University of Leeds, Leeds, UK*

The Three Gorges Project in the upper middle Yangtze River is composed of the Three Gorges (abbr. TG) Dam as main body and the Gezhouba (abbr. GZB) Dam as company. Besides generating power tremendously, the project has increased the shipping capacity remarkably by shifting the water level of upper stream much higher. Two locks and a ship lift in the TG dam and three locks in the GZB dam offer 6 canals for vessels to traverse the dams, which face heavy cargo traffic every day. As the two dams locate closely and have been managed centrally, it is necessary to co-ordinate the lockage scheduling for both dams to improve transport quality and save lockage resources including water and energy within given scheduling period. The problem was modelled as a deterministic bi-objective sequential 2D Next-Fit bin-packing where the small items are vessels and the bins are the locks. The transport quality objective was measured by total priority weighted waiting time of all request vessels, and the lockage resources objective was evaluated as the sum of lockage service usage multiplied by its corresponding lock chamber area. A parameterized VND algorithm with 4 neighborhood structures was proposed to practice different local search ranges. And a new lockage usage evaluation function was designed to intensify sensitivity of lockage usage objective to neighbor search. A rolling horizon version VND algorithm was generated to deal with longer period or larger scale traffic. Experiments were carried out based on four kinds of traffic flows with different area and shape distributions of vessels simulated according to the real historical lockage request data. The results showed remarkable optimization of each individual objective from the initial FCFS solutions. And the most efficient VND parameters have been selected out through the experiments. The experiments for bi-objective with different aggregation weights revealed that the transport quality diversity of solutions with similar lockage usage objective value and the positive correlation between the two objectives under some certain aggregation weights .

**Keywords**: Lockage scheduling; sequential 2D bin-packing; VND algorithm; bi-objective scheduling

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## A heuristics based on dynamic programming for the two-dimensional cutting problem

Assis, N. S. * and Rangel, S. †

* *São Paulo State University (UNESP);* † *São José do Rio Preto, Brazil*

Cutting and packing problems are part of the production planning process in many industries (e.g. paper, glass, furniture). In some furniture industries, large rectangular objects have to be cut into smaller rectangles and there is a limited work in process storage space. In this case there is interest in solving the constrained two-dimensional rectangular guillotine single large object placement problem (2DSLOPP). Several authors applied dynamic programming algorithms for solving the unconstrained two-dimensional cutting problem. However, for the constrained case this technique still presents some challenges due to the size of the state space. We propose a three-step heuristic based on the two-step method of Gilmore and Gomory (GGM) for the constrained 2DSLOPP. In the first step, a set of constrained knapsack problems are simultaneously solved by dynamic programming to obtain a set with the best strips. These strips are then combined to form a constrained 2D guillotine cutting pattern by solving an integer linear optimization problem (ILP), the second step of the method. In the proposed heuristic, the dynamic programming algorithm used in the first step is also applied to solve a relaxation of the ILP problem of the second step, which might result in an infeasible cutting pattern. A feasibility step is then applied to remove the items in excess. The results of a computational study with instances from the literature show that a feasible cutting pattern is obtained in less than one second and that the heuristic provided an optimal solution for most instances.

**Keywords**: two-dimensional cutting problem, guillotine, constrained, dynamic programming, heuristic.

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## Improved dynamic programming algorithms for large-scale two-dimensional guillotine cutting

MASONE Adriano*†, Russo Mauro‡†, Sforza Antonio*†, Sterle Claudio *†

* *Department of Electrical Engineering and Information Technology (DIETI), University Federico II of Naples;* † *Optimization and Problem Solving Laboratory (OPSLab), University Federico II of Naples;* ‡ *Hitachi Rail STS*

The unconstrained two-dimensional cutting (U2DC) problem consists in dissecting a rectangular sheet of material to extract an unlimited number of rectangular pieces with different size maximizing the achievable profit. In the guillotine variant, tackled in this work, only vertical and horizontal cuts dissecting a rectangle in two parts are allowed. The state of the art of the solving approaches for the guillotine U2DC problem is represented by dynamic programming procedures whose effectiveness and efficiency has been extensively proved on very large size problem instances. The research interest in this cutting problem and the relevance of these methods are also motivated by the relation between the guillotine U2DC, the non-guillotine U2DC and the constrained version of the problem (C2DC), where limits are imposed on the number of occurrences for each piece type. Indeed, on one side, the dynamic programming procedures return the optimal solution of the guillotine U2DC which represents also a lower-bound for the non-guillotine variant of the problem. On the other side, they return a full matrix of suitable C2DC upper-bounds for all the sub-rectangles of the sheet. In this context, we explore improvements of the state-of-the-art dynamic programming procedures for the U2DC. First, we apply new options and conditions for existing anti-redundancy strategies. Second, according to the effort of the modern home CPU suppliers, we introduce a parallelization scheme to improve the performance by integrating several cores. These improvements allow to effectively reduce the computation time needed to optimally solve very large size instances, as well as provide the optimal solution for several previously unsolved instances, with a small percentage increase of memory requirements. Further, we propose an integrated strategy to combine dynamic programming procedures with lower and upper-bounds. In particular, we exploit known and new lower-bounds, as well as improvements of upper-bounds present in literature. This integration allows also to transform the dynamic programming procedure into a heuristic algorithm to be used for solving extremely large size instances even on systems not equipped with large memory resources. Finally, a proper set of experimental results is provided to validate the proposed improvements and future work directions are given.
**Keywords**: guillotine cutting, dynamic programming, lower-bounds, upper-bounds.

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## Solving a large cutting problem in the glass manufacturing industry

Ramon Alvarez-Valdes*, Francisco Parreño†, Maria Teresa Alonso†
* *University of Valencia.*
† *University of Castilla -La Mancha*

The glass cutting problem proposed by Saint Gobain for the 2018 ROADEF challenge included some specific constraints that prevented the direct application of procedures developed for the standard cutting problem. On the one hand, the sheets to be cut had defects that made them unique and had to be used in a given order. On the other hand, pieces were grouped in stacks and the pieces in each stack had to be cut in order. There were also some additional characteristics due to the technology being used, especially the requirement for a three-staged guillotine cutting process. Taking into account the sequencing constraints on sheets and pieces, we developed a beam search algorithm, using a tree structure in which at each level the partial solution was increased by adding some new elements until a complete solution was built. We developed a randomized constructive algorithm for building these new elements and explored several alternatives for the local and the global evaluation. An improvement procedure, specifically designed for the problem, was also added. The computational study, using the datasets provided by the company, shows the efficiency of the proposed algorithm for short and long running times
**Keywords**: Cutting stock problem; Heuristics; Beam Search algorithm

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## Heuristic tree search for geometrical packing problems

Florian Fontan*, Luc Libralesso*
* *Université Clermont Auvergne, LIMOS*

We present an improved version of the Iterative Memory Bounded A* algorithm applied to geometrical packing problems. It was originally designed for the ROADEF/EURO challenge 2018, a guillotine Bin Packing Problem with Leftovers, defects, precedence constraints, and additional constraints on cuts. On this problem, this new version improves the solutions by more than 5% on average compared to the previous one. We also adapted it for other classical guillotine packing problems, i.e. two- and three-staged, exact, and non-exact guillotine packing problems with objectives Bin Packing, (Multiple) Knapsack, and Strip Packing. We show that the algorithm is competitive compared to dedicated algorithms on these variants and even yields better results for some of them.

Finally, we embedded it inside a column generation based heuristic to solve the pricing problem, making it possible to tackle the above variants - defects, two- and three-staged, exact and non-exact - with the objectives Cutting Stock and Variable-sized Bin Packing. These results show that heuristic tree search is a paradigm of choice for solving geometrical packing problems since it combines simplicity, effectiveness, and flexibility.
**Keywords**: Heuristic tree search, Column generation, Two-dimensional, Guillotine, Defects, Bin packing, Knapsack, Strip packing, Cutting stock, Variable-sized bin packing.

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## Mathematical models for a cutting problem in the glass manufacturing industry

Francisco Parreño[*], Ramón Alvarez-Valdes[†]
[*] *University of Castilla-La Mancha.*
[†] *University of Valencia.*

The glass cutting problem proposed by Saint Gobain for the 2018 ROADEF challenge includes some specific constraints that prevent the direct application of procedures developed for the standard cutting problem. On the one hand, the sheets to be cut have defects that make them unique and they must be used in a given order. On the other hand, pieces are grouped in stacks and the pieces in each stack must be cut in order. There are also some additional characteristics due to the technology being used, especially the requirement for a three-staged guillotine cutting process in which trimming is allowed under certain conditions. We approach the problem by developing and solving integer linear models. We start with basic models, which include the essential features of the problem, as a classical 3-stage cutting problem. Then, we add progressively new conditions to consider the order in the stacks, the minimum waste produced by guillotine cuts, and the possibility of trimming for some specific items. Finally, we add the conditions of the defects in the sheets. We propose the first integer linear model capable to work with trimming and defects. The results show that in most cases the optimal solution can be obtained for small problems taking into account all the constraints of the real problem.
**Keywords**: Integer programming, exact methods, level packing, bin packing

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## An efficient parallel algorithm to solve nesting problems using a semi-discrete representation

Sahar Chehrazad[*],Dirk Roose[*], Tony Wauters[*]
[*] *Department of Computer Science, KU Leuven*

We present an efficient algorithm to solve the two-dimensional cutting and packing problem, using a semi-discrete representation of irregularly shaped polygonal pieces, i.e. a piece is represented by a set of equidistant vertical line segments. The discretization method presented in (R. Akunuru and N. R. Babu, 2013) is improved by using a sweep line algorithm. The algorithm also ensures that the polygonal area, defined by the vertical line segments, is a minimal expansion of the polygonal piece, such that non-overlapping placement of the line segments guarantees a non-overlapping placement of the polygonal pieces. Non-overlapping placement of the line segments in a semi-discretized box by a bottom-left-fill method can be performed very efficiently because only operations on (vectors of) vectors are performed, allowing vectorization of loops. Also, whether the semi-discrete polygon can be placed at a specific position in the semi-discretized box can often be decided by checking only a few segments. In case rotation of the polygon is allowed, the placement of each polygon under several rotation angles is considered, as in E. Burke et al (2006). Final placement is done with the rotation that minimizes the required length of the box. Since the operations for each rotation are independent, they can be executed on different cores of a multi-core processor. An important parameter of the semi-discrete representation is the resolution, i.e. the distance between the vertical line segments. The resolution R influences the computational cost and the optimality of the placement, i.e. the required box length L. Experiments using the data sets from ESICUP indicate that with decreasing resolution R the size of the expansion decreases and the number of positions where the piece can be placed increases, typically leading to a lower box length. We propose a method to determine an appropriate resolution, based on some properties of the set of pieces. Experiments also indicate that, for a given 'computing budget', considering rotations typically lead to a larger improvement compared to using a finer resolution. The performance of the bottom-left-fill heuristic strongly depends on the ordering of the pieces to be placed A. M. Gomes and J. F. Oliveira (2002). The default ordering is largest-first, but our algorithm allows other orderings, obtained by swapping subset of pieces, which can lead to a shorter box length. Using greedy bottom-left-fill

placement, without rotation, with the pieces ordered largest-first, our algorithm, based on semi-discretization with a suitable resolution R, results in a box length L typically only a few percent larger than obtained with similar methods published in the literature, for several data sets from ESICUP, e.g. "shirts" (99 pieces). Since the computing times are always in the order of milliseconds on an Intel Core i7-7600U CPU (2.70GHz) with 2 cores (4 threads), our algorithm can be considered as a high-performance building block, to which several optimizations can be added, besides the already built-in rotations and re-ordering of the pieces.

**Keywords**: cutting and packing problem, semi-discrete representation, sweep line algorithm.

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## A general mixed integer programming model for rectangular guillotine cutting problems

Elsa Silva*, José F. Oliveira†, Leandro Mundim‡, Maria Antónia Carravilla†

* *INESC TEC.*

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

‡ *Optimized Decision Making (ODM), São Carlos - SP, Brasil*

In this work we study guillotine cutting problems from a single rectangular plate, where the items are rectangular, can have fixed orientation or can be rotated orthogonally and their value may or may not be proportional to their area. We propose new mathematical models for the following problems: Single Knapsack Problem, Single Large Object Placement Problem and Unbounded Single Large Object Placement Problem. The new models can be considered for guillotine problems with any number of stages, including the non-staged version. In addition, the new mathematical models do not require decision variables for the positioning coordinates of the items. We will present supporting algorithms for the mathematical formulations, as well as a set of valid inequalities that were added to the models to reduce symmetry and strengthen the formulations. Extensive computational experiments with benchmark instances from the literature were performed to evaluate the performance of the models considering different problem variants in order to compare the proposed models with the state-of-the-art formulations for the various problems.

**Keywords**: Guillotine cutting and packing problems; Mixed Integer Linear Programming Models

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## The constrained two-dimensional guillotine placement problem: the bottom-up models

Mateus Martin*, Reinaldo Morabito*, Pedro Munari*

* *Federal University of São Carlos (Brazil)*

The Constrained Two-dimensional Guillotine Placement Problem (C2GCP) addresses a rectangular large object of length L and width W, and a set $I = \{1, \ldots, m\}$ of different rectangular small item types. Each item type i has length $l_i$, width $w_i$, value $v_i$, and the maximum number of copies $u_i$ to be manufactured. The objective is to select and cut the most valuable subset of items from the large object, respecting the following requirements: (i) the overlap between small items is forbidden; (ii) the cuts are parallel to the object's edges and always generate two smaller rectangles, i.e., only orthogonal guillotine cuts are allowed; (iii) it allows up to $u_i$ copies, for each item type i in the cutting pattern. We address the unrestricted-staged case, i.e., cutting patterns with no limitation in the number of guillotine stages, and also d-staged patterns. According to the typology of Wäscher et al. (2007), the C2GCP is a variant of the Two-dimensional Single Large Object Placement Problem in which the cutting is of orthogonal guillotine-type and with a limitation of production for each item type.

The C2GCP is commonly related to industrial applications, such as the glass cutting, wood for customized furniture, marble and granite stones. Particularly, the problem arises in scenarios of low demands, in which few units of costly large objects should be cut to produce a few copies of small item types. Additionally, in scenarios where there are high demands such as those addressed by the Cutting Stock Problem (CSP), in which one generally seeks to minimize the number of large objects used, the C2GCP becomes the pricing problem in the context of the column generation algorithm. The guillotine restriction is also related to the industrial application according to the cutting device.

In this work, we propose linear and non-linear models for the C2GCP. These novel models define the cutting patterns as successive horizontal and vertical builds of the small items (Wang, 1983). For this reason, we say they follow the bottom-up packing approach. The main contributions of this work are: (i) the proposition of a pseudo-polynomial integer non-linear model for the C2GCP, and its equivalent Mixed Integer Linear Programming (MILP) formulation; (ii) the proposition of a compact integer non-linear model for the C2GCP, and its equivalent

MILP formulation; and, (iii) the development of non-linear inequalities, and their equivalent linear versions, for restricting the solution space of such models to d-staged cutting patterns. We performed computational experiments to compare the proposed models to the state-of-the-art model for the C2GCP (Furini et al., 2016). The results show that the proposed models, based on a bottom-up packing approach, lead to optimal or near-optimal solutions in reasonable processing times, even for scenarios that are intractable for the benchmark model.
**Keywords**: Two-dimensional cutting, Guillotine cuts, Mixed Integer Linear Programming, Bottom-up packing.

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## A matheuristic algorithm for the container stowage planning problem with practical constraints

Consuelo Parreño*, Hatice Çalık†, Ramó Álvarez-Valdés*, Rubén Ruiz‡
* *University of Castilla-La Mancha.*
† *University of Valencia.*
‡ *University of Southampton.*
⋆ *University of Leeds.*

Container terminals around the world are facing an ever-increasing volume of cargo transported, as well as an increase in the size of ships, which currently handle more than 20,000 TEU (e.g. MSC Mina and MSC Gülsün) With such large volumes, maximizing efficiency in container handling is essential for the global economy and for the environment, as reducing unnecessary port operations reduces carbon footprints.
Minimizing the number of loading and unloading operations in ports requires an efficient stowage plan describing where each container will be loaded on the vessel. This plan has two main objectives: (i) to load all assigned containers on board if they can feasibly fit on the vessel; (ii) and to minimize the number of unproductive movements in loading and unloading operations. We study the multi-port container ship stowage problem which consists of determining the position of the containers on board a ship along its route with the aim of minimizing the total number of unproductive movements required in loading and unloading operations.
The basic problem where all containers are of identical size and there are no additional weight constraints, called the Container Stowage Planning Problem (CSPP), has been well studied in the literature. In this paper a further step is taken by adding container sizes and weights and stability constraints to the problem, which makes it more realistic. We initially investigate how the difficulty in solving the problem changes with and without the consideration of container sizes and weight constraints. For this purpose, we provide integer programming formulations for the general problem as well as some special cases with identical container size and/or identical weights. To solve larger instances, we also propose a matheuristic algorithm, namely, an Insert-and-Fix algorithm, based on the decomposition of the proposed formulations.
We conducted an extensive computational study to test the performance of the integer programming models and the matheuristic proposed in this paper. The Insert-and-Fix algorithm, together with a constructive algorithm that gives the solver an initial solution in each iteration, provides very high-quality solutions for instances with up to 5000 TEUs.
**Keywords**: Stowage problem, Integer programming models, Matheuristics, Logistics.

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## The Integrated Production Planning and Cutting Stock Problem in Home-Textile Industry: ILP formulations and an $\epsilon-$Constraint approach

Khadija Hadj Salem*, Elsa Silva*, José.F. Oliveira*, Maria.A. Carravilla*
* *INESC TEC, Faculty of Engineering, University of Porto, Portugal.*

In the home-textile industry, the production process can generally be summarized in three phases including weaving, dyeing, and/or printing. This process is optional as the customer may decide on plain or patterned products. This industry relies also on the cutting of the produced fabric rolls (perhaps unrolled and folded in layers) to satisfy internal or external demands. In this study, we consider the Integrated Production Planning and Cutting Stock Problem (IPPCSP). Given a set of fabric rolls with predefined widths, a set of references, and a set of piece types, where each piece type has a rectangular shape with a specific width and length and a fixed demand to be respected, the problem aims to produce a set of specific lengths for the fabric rolls and generate the corresponding cutting patterns to cut all demanded pieces. The generated cutting patterns must be of the guillotine type and cuts are performed in two stages. The main objective is to minimize the total amount of the textile materials used in the production and equivalently the amount of textile materials waste. We proposed a set of four mathematical models, in terms of Integer Linear Programming (ILP), to exactly solve the problem, and used a set

of symmetry breaking inequalities and cutting planes to strengthen these different models. The quality of these models is evaluated through computational experiments on randomly generated instances. The numerical results show that current ILP formulations are capable of tackling the IPPCSP over a variety of axis across numerous tests. However, minimizing the number of total cuts in addition still one of the challenges that the home-textile industry faces. A bi-objective variant of the IPPCSP is then considered in this context. A mathematical model is proposed, and an epsilon-constraint method is applied to find the Pareto-optimal solutions. The conducted experiments in the same data-sets confirm the contribution importance to the decision-making on practice, allowing the decision-maker to evaluate different objectives.
**Keywords**: Home-textile industry, Production Planning; Cutting Stock; Waste (Trim loss); Integer Linear Programming; Symmetry Breaking Constraints; Cutting Planes; bi-objective Optimization Problem; Patterns; $\epsilon-$Constraint;

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## Computational and theoretical analysis of the Multi-Period Cutting Stock Problem with setups on cutting patterns

Eduardo Machado Silva*, Gislaine Mara Melega†, Kerem Akartunali‡ and Silvio Alexandre de Araujo*
* *Universidade Estadual Paulista "Júlio de Mesquita filho" (UNESP);* † *Universidade Federal de São Carlos (UFSCAR);* ‡ *University of Strathclyde*

In this study we tackled the multi-period cutting stock problem with setups on the cutting patterns (MPCSPs). This problem consists of determining the cutting patterns and multiplicities of the corresponding cutting patterns in each period of the planning horizon to satisfy customer demands while minimizing the costs associated with cutting pattern setup, inventory holding and objects consumed.
Although integrated decision problems have gained more attention over the last decade, there are only a small number of papers dealing with setups on cutting patterns with multiple periods in the literature. Our work makes important contributions in this domain. First, we present six formulations to provide a rather complete picture of alternative formulations for the problem. These six formulations are primarily a multi-period adaptation of known cutting stock problem formulations, such as pattern-based and arc-flow formulations (but also non-trivial integration of different models), and to the best of our knowledge, some of these formulations are proposed here for the first time in the literature. Secondly, we consider strengthening the formulations by using extended formulations and valid inequalities when applicable. More specifically, we use the facility location reformulation and the LS inequalities. Although these are effectively used methods in the lot-sizing domain, their application to MPCSPs is not trivial due to cutting patterns. Thirdly and most importantly, we present a thorough theoretical analysis investigating the strength of the various formulations given in the paper, providing a comparative ranking with respect to lower bounds to be expected from the formulations presented. To complement our theoretical analysis with an understanding of performance in practice, a brief computational analysis focusing primarily on solution times and lower bounds is given. We conclude through these final tests the strength of the formulations after the facility location reformulation as well as the better computational performance of the pattern-based and arc-flow formulations.
**Keywords**: Combinatorial Optimization, Integrated lot-sizing problems, Cutting Pattern Setup.

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## The machining torch movement for the rectangular sheet metal plasma cutting process.

Alvaro Neuenfeldt Júnior*, David Disconzi*, Gabriel Stieler*, Matheus Francescatto*
* *Federal University of Santa Maria, Brazil*

In the mechanical forming industry, the machining plasma cutting process of sheet steel and aluminum is developed by the movement of a torch with a cutting nozzle used to allow the passage of a gas at high temperature. For this work, the main objective is to compare the machining torch movement behavior considering the practical use of optimal and alternative solutions for the rectangular sheet metal plasma cutting process.
As a two-dimensional strip packing problem, a set of rectangular small items must be located inside a rectangular object with one dimension fixed and the other free, while minimizing the object's free dimension is the objective function. The small items can be rotated, must be positioned without overlapping each other, and must be completely contained inside the object.
The solutions comparison was developed considering three parameters: the total processing time, the effective distance traveled by the machining torch to cut the metal, and the movement distance traveled by the machining torch without cutting the metal. A total of 15 literature problem instances, separated into scenarios, were

used to verify the comparison parameters behavior. Alternative solutions were obtained using a bottom-left-fill constructive heuristic associated with a tabu search improvement heuristic, while a mixed Integer linear programming was modeled to obtain the optimal solution of each problem instance.
The sheet metal plasma cutting process conditions were simulated using settings and operational parameters as the feed rate, pierce height, and plunge rate, similar to the plasma arc cutting system verified on Hypertherm Powermax45 XP machines.
Computational results were obtained and will be presented.
**Keywords**: Strip packing problem, Machining torch movement, Plasma cutting process.

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## The meet-in-the-middle principle for cutting and packing problems

Jean-François Côté*, Manuel Iori†
* *Université Laval, Canada;* † *Università degli Studi di Modena e Reggio Emilia, Italy*

Cutting and packing (C&P) is a fundamental research area that models a large number of managerial and industrial optimization issues. A solution to a C&P problem basically consists in a set of one-dimensional or multi-dimensional items packed in/cut from one or more bins, by satisfying problem constraints and minimizing a given objective function. Normal patterns are a well-known C&P technique used to build solutions where each item is aligned to the bottom of the bin along each dimension. The rationale in their use is that they can reduce the search space while preserving optimality, but the drawback is that their number grows consistently when the number of items and the size of the bin increase. In this work we propose a new set of patterns, called meet-in-the-middle, that lead to several interesting results. Their computation is achieved with the same time complexity as that of the normal patterns, but their number is never higher, and in practical applications it frequently shows reductions of about 50%. The new patterns are applied to improve some state-of-the-art C&P techniques, including arc-flow formulations, combinatorial branch-and- bound algorithms, and mixed integer linear programs. The efficacy of the improved techniques is assessed by extensive computational tests on a number of relevant applications.
**Keywords**: cutting and packing, normal patterns, bin packing problem, orthogonal packing

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## A Lookahead Matheuristic for the Unweighed Variable-Sized Two-dimensional Bin Packing Problem

Sergey Polyakovskiy*, Rym M'Hallah†
* *School of Information Technology, Deakin University, Australia;* † *Department of Engineering, King's College London, The United Kingdom*

The unweighed variable-sized two-dimensional guillotine bin packing problem consists in packing without overlap small rectangular items into large non-identical rectangular bins, with the items obtained via guillotine cuts. It minimizes the waste of the used bins. It is herein approximately solved using a hybrid matheuristic that applies a sequence of low-level mixed-integer programs that reserve space for unpacked items and that are guided by feasibility constraints and upper bounds on the objective function. The embedded constraints constitute a lookahead mechanism that prohibits the investigation of infeasible directions and constrains the search to improving ones. The matheuristic further employs high-level diversification and intensification mechanisms. The diversification incorporates a sequential value correction algorithm that tags a pseudo-price to each item and searches for a solution that maximizes the sum of pseudo-prices. The intensification is a local search that investigates the neighbourhood of promising solutions. The extensive computational experiments provide evidence of the good performance of the proposed matheuristic both in terms of solution quality and runtime. Indeed, the results outperform the state-of-the-art results.
**Keywords**: Bin Packing; Packing Heuristic; Matheuristics; Lookahead Search; Feasibility Constraints

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## Optimized packing ellipses and its application for Additive Manufacturing

T. Romanova*, Y. Stoyan*, A. Pankratov*, I. Litvinchev‡, J.A. Bennell†
* *Institute for Mechanical Engineering Problems of the National Academy of Sciences of Ukraine, Department of Mathematical Modelling and Optimal Design , Ukraine.*

‡ *Nuevo Leon State University (UANL), Faculty of Mechanical and Electrical Engineering, San Nicolas de los Garza, Mexico.*
† *University of Leeds, UK*

The paper studies a layout problem of variable number of ellipses with variable sizes placed into an arbitrary disconnected polygonal domain with maximum packing factor. The ellipses can be continuously translated and rotated. Restrictions on the dimensions of the ellipses are taken into account. Tools for the mathematical modeling of placement constraints (distance constraints between ellipses and containment of ellipses into a polygonal domain) using the phi-function technique are introduced. The tools make it possible to formulate the layout problem in the form of MIP model that is equivalent to a sequence of nonlinear programming subproblems. We develop a new solution algorithm that involves the feasible starting point algorithm and optimization procedure to search for efficient locally optimal solutions of the layout problem. This algorithm can be used in the design of parts for «support-free» additive manufacturing, taking into account the conditions for its static/ dynamic strength. Results of the algorithm implementation for a topologically optimized flat part with the analysis of a stress state are provided.
**Keywords**: ellipses; layout; phi-function technique; mathematical model; nonlinear optimization; additive manufacturing

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## A ray-casting approach for collision detection in 3D irregular cutting and packing problems

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

Extraction of maximum three-dimensional, irregular items from larger objects remains one of the most challenging categories of cutting and packing problems. The reason for this is the combination of both computationally costly geometric computations and the exponentially increasing size of the solution space due to the dimensionality of the problems in this category. Exact optimization methods require an unreasonable amount of computation time for larger, real-world instances. Therefore heuristic algorithms are often used in practice to find good solutions. Generally, these algorithms iteratively evaluate whether or not solutions are feasible by testing if items intersect each other or the larger object. As a result, the geometric computations quickly become the limiting factor for evaluating as many solutions as possible in a reasonable amount of time.
This research will explore the possibility of leveraging the ray-casting capabilities of recent GPU architectures to detect intersections between objects represented by triangular meshes. The objective is to enable faster sequential evaluation of different solutions. In particular, we focus on the use case where heuristics are used for extracting items with maximum volume from solid, three-dimensional shapes. The implementation of this methodology employs NVIDIA's CUDA and OptiX frameworks. We will investigate if this approach can outperform the common approach, based on triangle-triangle intersection tests and bounding volume hierarchies, on both GPU and CPU platforms. To help stimulate and standardize future research, we also introduce a set of instances with three-dimensional objects of various shapes and levels of detail.
**Keywords**: maximum volume extraction, collision detection, ray-casting, GPU computing

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## Cutting Stock Problem with due dates and variable processing times

Felipe Kesrouani Lemos*, Adriana Cristina Cheri*, Silvio Alexandre de Araujo*
* *University of the State of São Paulo (UNESP)*

This work approaches minimizing tardiness costs integrated to the cutting stock problems on the one-dimensional cutting processes. It has been motivated by an aeronautic factory, in which tardiness on assembly lines can be as costly as raw material waste. In particular, we explore the case that processing times of cutting patterns depend on the number of items allocated on each of them. Recent literature approaches processing times independent of items assigned to the cutting pattern, which can be suitable for some cutting processes, as paper cutting with knives. On the other hand, some processes, like presses or saws, can have different processing times according to their items. This case remains with few approaches. Thus, the contribution of this work to literature is: (i) exploring the case in which processing times of cutting patterns are variable; (ii) proposing a mathematical formulation that combines the standard objective of minimizing the number of objects used with a scheduling term penalizing the tardiness of the cutting operations; (iii) proposing a solution method based on column generation

that considers not only the knapsack problem but also the pattern processing time; (iv) improving lower bounds throughout a procedure using dynamic programming. Computational tests were performed in a real instance and randomly generated instances. The real instance was based on data from an aeronautic factory. Compared to the incumbent empirical method, the formulation could deliver an 11.2% reduction in material waste and a 52.0% reduction in tardiness costs. Randomly generated instances were designed varying parameters of (i) size of the items, (ii) size of the demands, (iii) weight of tardiness costs compared to raw material, and (iv) tightness of due dates. All of them were generated with 20 items. A total of 180 instances were tested with the method proposed with a limitation of 60 seconds after column generation to achieve practical purposes. The average gap was 7.8Future research could advance on instances with more item types and consider setup times on the processing times of the cutting patterns. Some specific parameters that delivered worse results could also be addressed with tailored methods for their cases.
**Keywords**: Home-textile industry, Production Planning; Cutting Stock; Waste (Trim loss); Integer Linear Programming; Symmetry Breaking Constraints; Cutting Planes; bi-objective Optimization Problem; Patterns; $\epsilon-$Constraint;

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## A Goal-Driven Ruin and Recreate Heuristic for the 2D Variable-Sized Bin Packing Problem with Guillotine Constraints

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

This work considers the two-dimensional bin packing problem with guillotine constraints. The problem requires a set of rectangular items to be cut from larger rectangles, known as bins, while only making use of edge-to-edge (guillotine) cuts. The goal is to minimize the total bin area needed to cut all of the required items. Variants of the problem with $90^o$ rotation of items and/or a heterogeneous set of bins (variable-sized bins) are also addressed. A novel heuristic is introduced which attempts to improve the solution at each iteration by removing and reinserting items into the bins in a greedy fashion, guided by a cost function. Each time the algorithm reaches a complete solution with a certain total bin area, it is henceforth forced to find new solutions which use less bin area. The search can be described as being goal-driven since it continuously strives to create complete solutions with an ever-decreasing limit of available bin area. As a result, most of the time, the heuristic will be unable to fit all items into the available bins and will therefore be working with infeasible solutions. After each run, items which could not be positioned are automatically reconsidered for reinsertion during the next run. In order to reach complete solutions, a cost function was designed to steer the heuristic towards feasibility. Unlike most other heuristics for this problem, the focus lies primarily on the improvement phase rather than the constructive aspect. When testing the proposed heuristic on benchmark instances from the literature, it outperforms the current state-of-the-art algorithms in terms of solution quality for all variants of the problem considered.
**Keywords**: 2D Bin Packing, Guillotine, Heuristic, Ruin and Recreate, Variable-sized bins

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## A Branch-and-Price Algorithm for the Multiple Knapsack Problem

Olivier Lalonde*, Jean-Franȩis Côté†, Bernard Gendron*
* *Université de Montréal, Canada*
† *Université Laval, Canada*

The Multiple Knapsack Problem (MKP) is a combinatorial optimization problem with several applications. It consists of packing some subset of n items into m knapsacks such that the total profit of the chosen items is maximum. A novel Lagrangian relaxation based on a reformulation of the problem is presented, and it is proven that it dominates all commonly used relaxations for this problem. A branch-and-price algorithm (BP-MKP) is then derived from it, which takes advantage of the fact that the novel Lagrangian relaxation makes it possible to effectively control whether an item is included in some knapsack or not. An improved algorithm for solving the resulting packing subproblems is also introduced. Computational experiments then show that the new approach achieves state-of-the-art results.
**Keywords**: Multiple Knapsack Problem, Branch-and-Price, Lagrangian relaxation.

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# The 3D bin packing problem with weight distribution constraints

Pauline Pochte*, Mario Schwerdt*, Henriette Koch*
* *4flow AG, Berlin, Germany*

4flow offers an integrated standard software for supply chain design and transportation planning. One of the functions included in the software is a 3D freight-planning tool. It solves a 3D bin packing problem with the objective of minimizing the total loading meters. In order to provide load plans that are as realistic as possible, different constraints are observed, e.g. support, weight or priority constraints. The packing problem is tackled with different algorithms, one of which is a wall-building algorithm.

The consideration of weight distribution, in particular the allowed axle load, is a frequently addressed requirement to the 3D planner. However, a usual problem in practice is the accuracy of the available data. Therefore, we developed different approaches how the weight distribution can be considered. The first approach is a segmentation of the loading area into smaller areas with different maximum loads. This approach is particularly beneficial if the actual axle positions and allowed loads are not known, which is usually the case if the trucks belong to another company. Secondly, we can consider the truck's load distribution plan. The consideration of those constraints will be presented based on the wall-building algorithm.

Real-life instances where the axle load would be violated without this approaches are used to analyze the effects of the different approaches on the overall solution quality.

The algorithms produce solutions that do not violate the axle load and use on average less than 30% additional space in a run time that is increased by just 10%.

**Keywords**: bin packing, weight distribution, axle load

# List of Participants

**Alexandre de Araujo , Silvio**
Universidade Estadual Paulista-UNESP, Brazil.
Brazil
silvio.araujo@unesp.br

**ALONSO MARTÍNEZ , MARÍA TERESA**
University of Castilla-La Mancha
Spain
mariateresa.alonso@uclm.es

**Alvarez-Valdes , Ramon**
University of Valencia
Spain
ramon.alvarez@uv.es

**BAILLEUX , Jérémy**
OMP

jbailleux@omp.com

**Bennell , Julia**
Unversity of Leeds
UK
J.Bennell@leeds.ac.uk

**Bochet , Marie**
OMP

mbochet@omp.com

**Carravilla , Maria Antónia**
University of Porto
Portugal
mac@fe.up.pt

**Chehrazad , Sahar**
KU Leuven
Belgium
Sahar.Chehrazad@cs.kuleuven.be

**Cherri , Adriana Cristina**
Unesp - Bauru/SP
Brazil
adriana.cherri@gmail.com

**Clautiaux , François**
Institute de Mathematiques, Bordeaux
France
francois.clautiaux@math.u-bordeaux.fr

**Côté , Jean-François**
Université Laval
Canada
jean-francois.cote@fsa.ulaval.ca

**Fernando Oliveira , José**
INESC TEC, Faculty of Engineering, University of Porto
Portugal
jfo@fe.up.pt

**Fontan , Florian**
Artelys
France
florian.fontan@artelys.com

**Gajda , Mikele**
University of Lausanne
Switzerland
mikele.gajda@unil.ch

**Galrão ramos , António**
INESC TEC and Porto School of Engineering
Portugal
agr@isep.ipp.pt

**Gardeyn , Jeroen**
KU Leuven
Belgium
jeroen.gardeyn@kuleuven.be

**Giménez Palacios , Iván**
University of Castilla-La Mancha
Spain
Ivan.Gimenez@uclm.es

**HADJ SALEM , Khadija**
CEGI, INESC TEC, Porto
Portugal
hadj.salem@inesctec.pt

**J. Lastra-Diaz , Juan**
LECTRA
Spain
j.lastra@lectra.com

**Kesrouani Lemos , Felipe**
São Paulo State University (UNESP)
Brazil
felipeklemos@gmail.com

**Király , Hédi**
University of Duisburg-Essen, Mercator School of Management
Germany
hedi.kiraly@uni-due.de

**Koch , Henriette**
4flow
Germany
h.koch@4flow.de

**Krebs , Corina**
Otto von Guericke University, Magdeburg
Germany
Corinna.Krebs@ovgu.de

**Lalonde , Olivier**
Université de Montréal (DIRO)
Canada
olivier.lalonde.1@umontreal.ca

**Lamas , Carlos**
University of Southampton
UK
c.lamas-fernandez@soton.ac.uk

**Libralesso , Luc**
Clermont-Auvergne University
France
luc.libralesso@uca.fr

**Liu , Kelvin**
University of Melbourne
Australia
cliu2@student.unimelb.edu.au

**Machado Silva , Eduardo**
Universidade Estadual Paulista "Júlio de Mesquita Filho", UNESP
Brazil
eduardo.msilva094@gmail.com

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

**Masson , Renaud**
OMP

rmasson@omp.com

**Monaci , Michele**
University of Bologna
Italy
michele.monaci@unibo.it

**Moons , Elias**
OMP

emoons@omp.com

**Neuenfeldt Júnior , Alvaro**
Federal University of Santa Maria (UFSM)
Brazil
alvaroj.eng@gmail.com

**Nogueira do Nascimento , Douglas**
Departamento de Engenharia de Produção, FEB, UNESP, Bauru, SP, Brasil
Brazil
douglas.nogueira@unesp.br

**Olsson , Jonas**
Linköping University
Sweden
jonasolovolsson@gmail.com

**Paquay , Célia**
HEC - Liège, Management School of the University of Liege
Belgium
cpaquay@uliege.be

**Parreno , Consuelo**
University of Castilla-La Mancha
Spain
Consuelo.Parreno@uv.es

**Parreno , Fran**
University of Castilla-La Mancha
Spain
francisco.parreno@uclm.es

**Pereira Martin , Mateus**
Federal University of São Paulo
Brazil
mpmartin@unifesp.br

**Pierini , Livia Maria**
UNICAMP
Brazil
liviam.pierini@gmail.com

**Pochte , Pauline**
4flow
Germany
p.pochte@4flow.de

**Polyakovskiy , Sergey**
School of Information Technology, Deakin University
Australia
sergey.polyakovskiy@deakin.edu.au

**Potts , Chris**
University of Southampton
UK
C.N.Potts@soton.ac.uk

**Quttineh , Nils-Hassan**
Linköping University
Sweden
nils-hassan.quttineh@liu.se

**Rakotonirainy , R. Georgina**
Statistical Sciences Department, University of Cape Town
South Africa
rosephine.rakotonirainy@uct.ac.za

**Rangel , Socorro**
UNESP - Universidade Estadual Paulista
Brazil
socorro.rangel@unesp.br

**Romanova , Tatiana**
IPMach of the National Academy of Sciences of Ukraine
Ukraine
tarom27@yahoo.com

**Roose , Drik**
KU Leuven
Belgium
Dirk.Roose@kuleuven.be

**Russo , Mauro**
Hitachi Rail STS; Optimization and Problem Solving Laboratory (OPSLab), University Federico II of Naples
Italy
ma.russo@unina.it

**Samuel Assis , Nícolas**
São Paulo State University (UNESP)
Brazil
nicolas.s.assis@unesp.br

**Schwerdt , Mario**
4flow
Germany
m.schwerdt@4flow.de

**Shimoda , Tomohiro**
Independent

simotsimot@gmail.com

**Silva , Elsa**
INESTEC TEC
Portugal
emsilva@inesctec.pt

**Tollenaere , Jonas**
KU Leuven
Belgium
jonas.tollenaere@kuleuven.be

**Wauters , Tony**
KU Leuven
Belgium
Tony.Wauters@cs.kuleuven.be

**Xiaopan , Zhang**
Wuhan University of Technology
China
zxp.china@gmail.com