13th ESICUP Meeting

Ibiza, Spain, May 18 – 20, 2016

EURO Special Interest Group
on Cutting and Packing

The Association of European
Operational Research Societies

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ESICUP – EURO Special Interest Group on Cutting and Packing

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Welcome

Dear Friends,

Welcome to the 13th 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 in Wittenberg (Germany), Southampton (United Kingdom), Porto (Portugal), Tokyo (Japan), L'Aquila (Italy), Valencia (Spain), Buenos Aires (Argentina), Copenhagen (Denmark), La Laguna (Spain) and Lille (France), Beijing (China), Portsmouth (United Kingdom), and this 13th meeting is now held in Ibiza (Spain).

Once again, this meeting will serve as an instrument for the development of research and the dissemination of knowledge in our field. Twenty four 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.

Ibiza is an island in the Mediterranean Sea, 150 kilometers off the coast of the city of Valencia, in eastern Spain. It is the third largest of the Balearic Islands, an autonomous community of Spain. The island has been a meeting place and point of exchange for different cultures. Carthaginians, Phoenicians, Romans, Vandals, Byzantines, Visigoths, Muslims, Catalans and so on have occupied Ibiza. This cultural wealth has influenced its cultural singularity and landscape. Ibiza is full of marvelous places, which together with the character of its inhabitants, make it a special island in the Mediterranean.

Its largest city is Ibiza Town, in which the meeting takes place. The city concentrates a large number of services and activities but their evolution has taken place in harmony with the traditional districts, such as La Marina, El Eixample or Dalt Vila, which is preserved in an exceptional state and has been declared World Heritage. We strongly encourage you to stay a few days longer and enjoy the city and the island.

Finally, we would like to express our sincere thanks to the members of both the Program Committee and the Organizing Committee. Without their commitment and enthusiasm this meeting wouldn't have been possible.

We wish all of you a successful conference and a very pleasant stay in Ibiza!

Ramón Álvarez-Valdés
University of Valencia
Program Chair

A. Martinez Sykora
University of Southampton
Organizer Chair

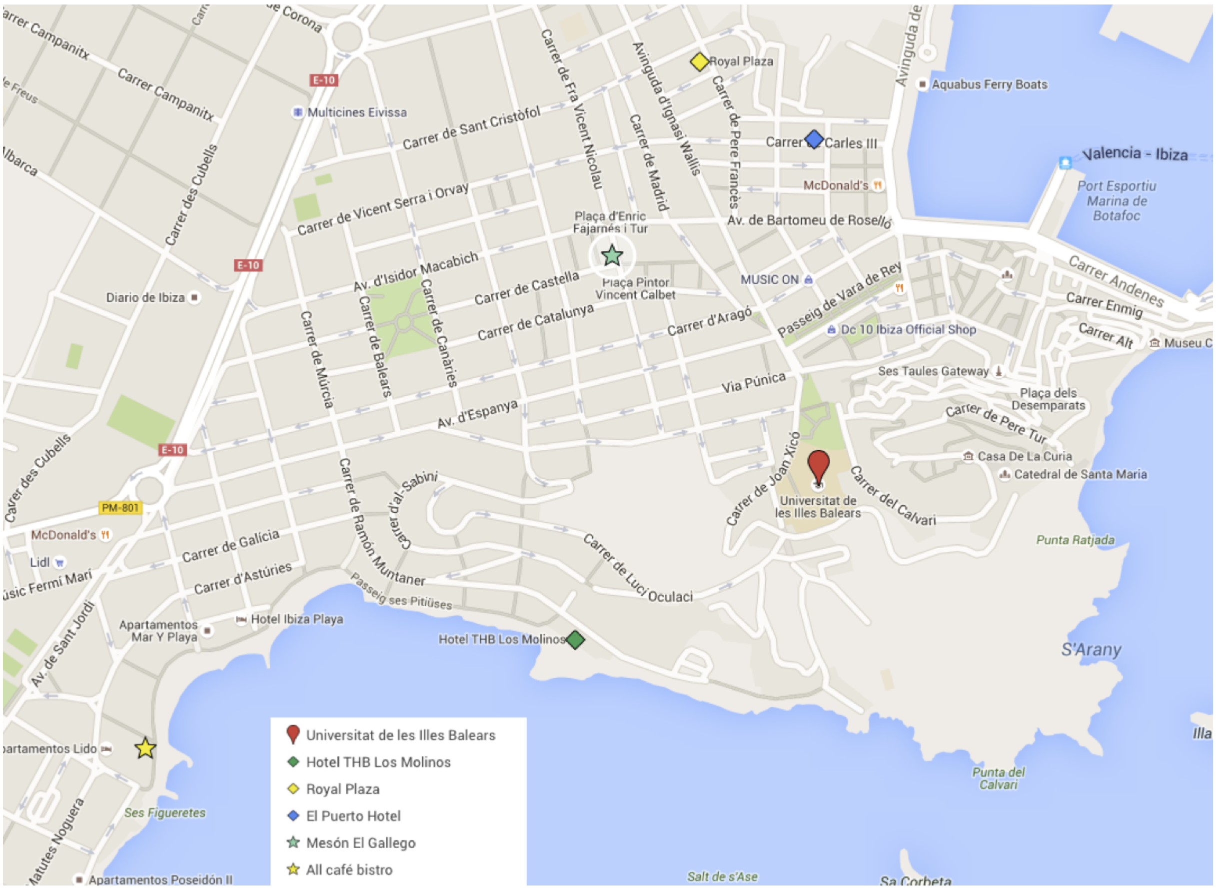
Information for Conference Participants

MEETING VENUE

The 13th ESICUP Meeting will be held at the University of the Balearic Islands in Ibiza (Centre of Ibiza and Formentera, located close to city centre).

Address:

Antiguo edificio de la Comandancia Militar
Carrer del Calvari, 1
07800 Ibiza



REGISTRATION

The registration desk will be located in the meeting venue, where you will collect your name badge for the event. Registration will be open from 8.45am to 9.15am, May 19, 2016 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 as a backup.

- **Length of Presentation**
  22.5 minutes for each talk, including approx. 5 min for 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

Participants coming from an institution that belongs to the Eduroam program can get connected to the "eduroam" wireless network. In order to get connected to this network, the credentials (username/password) served by the foreign institution must be used.
Other participants should use the following steps:
1. Connect to the WiFi (or SSID) "uib_(key=password2014)" network
2. Introduce the key "password2014"
3. Activate the dynamic IP configuration (DHCP) if needed
4. Open a web browser and try to access a website.
5. Insert the following credentials in the web page that will appear:
   Username: ESICUP   Password: eivissa2016

DIETARY, MOBILITY AND OTHER REQUIREMENTS

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

GET-TOGETHER EVENING

Takes place on Wednesday 18th May, from 19:30, at:
Mesón El Gallego,
Carrer del Bisbe Huix, 19, 07800 Ibiza
(see map in last page).
Note: refreshments, snacks and meals available on a pay-yourself basis.

CONFERENCE DINNER

Takes place at Restaurant *All Ibiza* on Thursday 19th May, from 20:00.
Address: Paseo ses Pitiusas, 28, 07800 Ibiza
(see map in last page).
Notes:
– three courses (starter, main and dessert), drink included;
– appears in Google as "All cafe bistro", its old name;
– 20 minutes walking from the meeting venue and city center.

EXCURSION TO LAS SALINAS BEACH

The Las Salinas (Ses Salines) National Park, is situated in area that lies between southern Ibiza and northern Formentera, and covers an area of 1,78652 hectares onland and 13,61180 hectares offshore. A wide variety of differing natural features can be found, from salt lakes and beaches to lunar cords with centuries-old ghost trees, cliffs and rocky coastlines.
Belonging to the national park, the Las Salinas Beach is a long expanse of soft golden sand surrounded by a nature reserve including sand dunes, pine forests and spectacular salt flats. The sea is particularly salty here, which makes it incredibly easy to stay afloat when swimming.
We plan to have a nice walk (2.5Km approx.) and a deserved refreshment. Alternatively, if you want to enjoy the Mediterranean Sea, make sure you bring the necessary beach equipment.
Trip - Excursion, by regular bus (L11), to Las Salinas beach (pay-yourself basis).
`http://ibizabus.com/ibiza/lineas/`

CITY AND MOVING AROUND

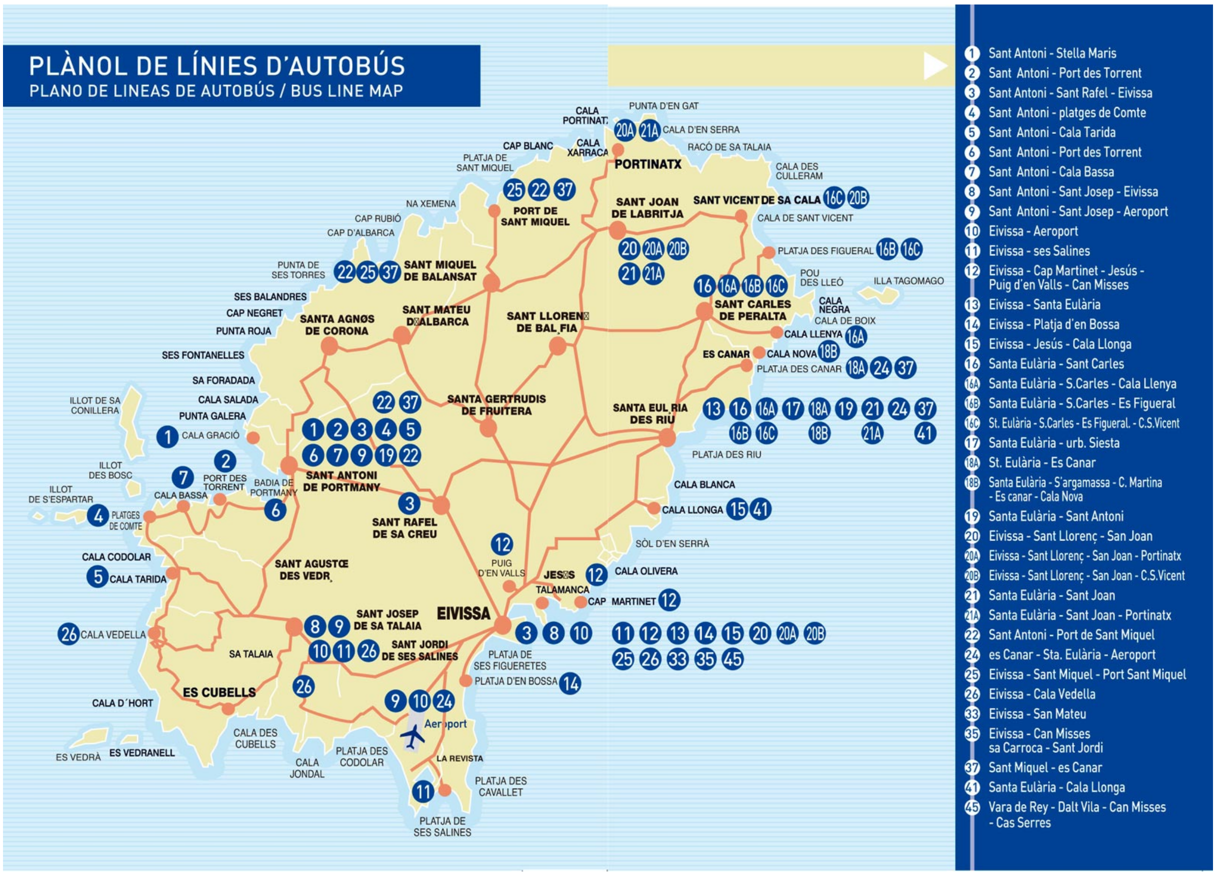
- **About Ibiza**
  Ibiza is located in the Mediterranean Sea, to the east of the Spanish Peninsula, and is one of the Balearic Islands. Ibiza, which covers 572 km2, is a whole world in miniature and stretches from the coast inland. Ibiza with its smooth relief along with Formentera, make up the so-called Pitiusas islands. The Greeks referred to them as the islands of the pines, Ibiza itself being the larger of the two.
  A meeting place and point of exchange for different cultures. Carthaginians, Phoenicians, Romans, Vandals, Byzantines, Visigoths, Muslims, Catalans and so on have occupied Eivissa. This cultural wealth has influenced its cultural singularity and landscape. In the last 40 years, the needs of a tourism – at times excessive – have occupied the territory, transforming a poor island from

which many of its inhabitants had to emigrate into a source of wealth. Society develops quickly towards modernity. Eivissa-Ibiza is full of marvellous places, which together with the character of its inhabitants, make it a special island in the Mediterranean. For more information, please visit `http://www.ibiza.travel/en/index.php`.
`http://www.eivissa.es/`

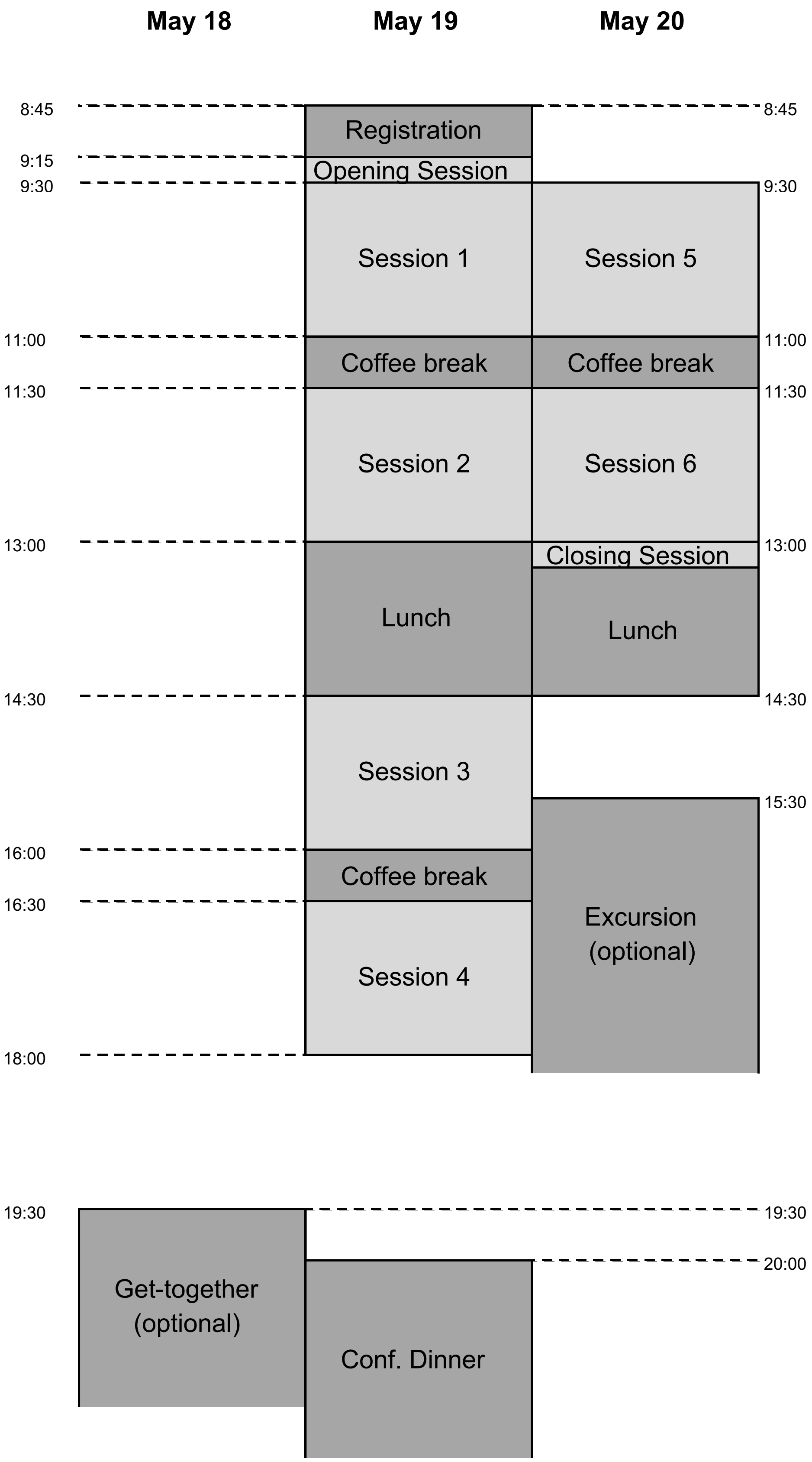
- **Airport**
  Ibiza Airport serves two Balearic Islands, namely Formentera and Ibiza itself. The airport is situated 7.5 km out of Ibiza Town, the south-west of the city.
  `http://www.ibizaairport.org`

- **By Taxi**
  Radiotaxi Eivissa: +34 971 39 84 83
  Radiotaxi Sant Josep: +34 971 80 00 80
  Radiotaxi San Antoni: +34 971 34 37 64
  Radiotaxi Santa Eularia: +34 971 33 33 33
  Radiotaxi Sant Joan: +34 971 33 33 33

- **Buses**
  `http://ibizabus.com/ibiza/lineas/`



Program Overview



Scientific Program Schedule

Thursday, May 19th

9:15 – 9:30

Opening Session

Welcome Address

9:30 – 11:00

Session 1 *Chair: Julia Bennell*

1.1 – An exact algorithm for Nesting Problems
Julia Bennell, A. Martinez-Sykora, Ramon Alvarez-Valdes

1.2 – A Beam Search Algorithm for the 2-Dimensional Bin Packing Problem
J. A. Bennell, M. Cabo, A. Martinez-Sykora

1.3 – H4NP, a general heuristic for two-dimensional nesting problems with fixed size containers
Leandro R. Mundim, Marina Andretta, José F. Oliveira, Maria Antónia Carravilla

1.4 – Algorithms for the 2-D Irregular multiple bin size bin packing problem
Ranga P. Abeysooriya, Julia A. Bennell, Antonio Martinez-Sykora

11:30 – 13:00

Session 2 *Chair: Gerhard Wäscher*

2.1 – JNFP: a robust and open-source Java based nofit polygon generator library
Tony Wauters, Stiaan Uyttersprot, Eline Esprit

2.2 – A BRKGA based approach for a two-dimensional cutting problem with defects
José Fernando Gonçalves, Gerhard Wäscher

2.3 – Equivalent transformations for the d-dimensional Orthogonal Packing Problem
Vadim M. Kartak, Artem V. Ripatti

2.4 – Dynamic pricing in the ferry industry
A. Martinez-Sykora, C. Bayliss, C.Currie, M. So, J.A. Bennell

14:30 – 16:00

Session 3 *Chair: José Fernando Oliveira*

3.1 – A best fit decreasing algorithm for the three dimensional bin packing problem with transportation constraints
C. Paquay, S. Limbourg, M. Schyns

3.2 – Generating real-world-like problem instances
Felix Brandt

3.3 – A review and model proposal for the balance and weight limit constraints on road transport
António G. Ramos, Elsa Silva

3.4 – Analysis of test instances for Container Loading Problems
Elsa Silva, António G. Ramos

16:30 – 18:00

Session 4 *Chair: A. Martinez-Sykora*

4.1 – Analysis of solution representation for the rectangle packing problem
Shinji Imahori

4.2 – Solving methods for a two-dimensional knapsack problem
Quentin Viaud, François Clautiaux, Ruslan Sadykov, François Vanderbeck

4.3 – Creating Worst-Case Instances for Upper and Lower Bounds of the Two-Dimensional Strip Packing Problem
Torsten Buchwald, Guntram Scheithauer

4.4 – A new heuristic for the rectangular two-dimensional strip packing problem
Alvaro Luiz Neuenfeldt Júnior, Elsa Silva, Maria Antónia Carravilla

Friday, May 20th

9:30 – 11:00

Session 5 *Chair: Ramon Alvarez-Valdes*

5.1 – A savings heuristic for the 3L-VRP with backhauls and time windows
Henriette Koch, Andreas Bortfeldt, Gerhard Wäscher

5.2 – Guide & Observe for the ESICUP 2015 Challenge problem: an analysis of objective functions
Eline Esprit

5.3 – Solving the stowage slot planning problem with GRASP
Francisco Parreño, Ramón Alvarez-Valdes, Dario Pacino

5.4 – Models and algorithms for a multi-port container ship stowage problem
Consuelo Parreño, Ramon Alvarez-Valdes, Francisco Parreño

11:30 – 13:00

Session 6 *Chair: A. Miguel Gomes*

6.1 – Heuristics for the Bitmap Shape Packing Problem: Efficient Implementations and Placement Strategies
Yannan Hu, Sho Fukatsu, Hideki Hashimoto, Shinji Imahori, Mutsunori Yagiura

6.2 – A new global optimization method based on clustering and parabolic approximation for the shoe nesting on leather
Fatih Ahmet Şenel, İhsan Pençe, Bayram Cetişli

6.3 – Raster Approach to the Nesting Problem
A. Miguel Gomes, André Kubagawa Sato, Thiago Castro Martins, Marcos Sales Guerra Tsuzuki

6.4 – Voxel based heuristics for 3D irregular packing
Carlos Lamas-Fernandez, Julia A. Bennell, Antonio Martinez-Sykora

13:00 – 13:10

Closing Session

Closing Notes

Social Program

- **Get-together Evening**
  May 18, 2016, from 19:30,
  Mesón EL Gallego,
  Address: C/ Obispo Pablo Huix 19, 07800 Ibiza
  Note: refreshments, snacks and meals available on a pay-yourself basis.

- **Conference dinner**
  May 19, 2016, from 20:00,
  Restaurant *All Ibiza*
  Address: Paseo ses Pitiusas, 28, 07800 Ibiza
  Notes: three courses (starter, main and dessert), drink included;
  included in the registration fee.

- **Excursion to Las Salinas**
  May 20, 2016, From 15:30,
  Excursion, by regular bus (L11), to Ses Salinas (pay-yourself basis).

Abstracts

1.1
An exact algorithm for Nesting Problems

Julia Bennell*, A. Martinez-Sykora*, Ramon Alvarez-Valdes†
* *University of Southampton,* † *University of Valencia*

In this work we present two mixed integer linear programming formulations for the two-dimensional strip packing problem with irregular shapes, also known as nesting problems. For many benchmark data sets, the pieces are allowed to be rotated by a finite set of angles. In these problems there are two families of inequalities, the containment inequalities and the no-overlap inequalities. It is well known that the no-overlap inequalities considerably increase the difficulty of solving these models. Therefore, we explore two alternative ways to formulate the no-overlap constraints that permit a given set of orientations of the pieces.
The first model uses the nofit polygons to write the no-overlap inequalities and introduce binary variables to select the orientation used by the pieces. The number of binary variables needed to guarantee that pieces do not overlap depends not only on the complexity of shape, but also on the number of rotations allowed. For each pair of pieces we consider all the nofit polygons given by all rotations of both pieces, leading to a high number of variables for each pair of pieces. However, the binary variables that guarantee that the pieces do not overlap is directly related to the binary variables that define the piece orientation. Hence, fixing the no-overlap binary variable indicates the values of the orientation binary variables giving a tighter set of inequalities in the model.
In the second model we introduce a new use of the nofit polygon in which different nofit polygons are combined. The core of this approach is to divide the outer part of all the nofit polygons into convex polygons (slices) in such a way we know the angles of rotations allowed in each slice. In general, this approach needs a lower number of binary variables and once a no-overlap binary variable is fixed the feasible region is more tightly constrained. However, the binary variables for no-overlap and orientation are not linked as in the first approach and as a result the inequalities used to force each piece to use a given angle of rotation are weaker.
Therefore, we present a combined method that selects the approach for setting the no-overlap constraints for a pair of pieces depends on the number of variables needed in the MIP. We prove the efficiency of both models in a set of small instances, proving optimality in instances up to 10 pieces with 4 angles of rotations.
Keywords: nesting problems, exact algorithms, irregular shapes

1.2
A Beam Search Algorithm for the 2-Dimensional Bin Packing Problem

J. A. Bennell*, M. Cabo†, A. Martinez-Sykora*
* *University of Southampton, United Kingdom,* † *Instituto Tecnológico Autónomo de México (ITAM), Mexico*

In this work, we tackled a two-dimensional bin packing problem with guillotine cuts. The majority of papers that tackle this problem consider only rectangular shaped pieces. In our work the pieces we are cutting are irregular, thus the optimal cut is not necessarily orthogonal to the edges of the bin. Moreover, pieces can be freely rotated, and reflected. There are only a few papers that tackle this problem, and the best results so far are achieved by means of a constructive heuristic that uses a MIP to add a piece to the layout. This method produces good solutions in terms of bin utilization, but it is very time consuming, and unattractive to small business since it requires expensive specialised software.
We develop a beam search heuristic that proves to be competitive in terms of bin utilization and faster than the previous MIP. Beam Search is a heuristic that uses a tree structure of nodes and branches. Each node represents a partial solution at each level of the tree. Previous implementations of beam search for cutting problems build a single stock sheet by adding a new piece to the layout at each level. In our implementation, we pack multiple bins where each node represents a packed bin.
We develop a fast packing heuristic to create each node. It considers two criteria to place pieces together. The first criterion considers the maximum utilization of the convex hull of the candidate piece and the current layout. The second criterion considers the separate areas of the stock sheet generated by a complete guillotine cut and tries to place the remaining pieces in the empty area.
The packing algorithm provides a fast and effective heuristic that produces competitive results for the benchmark problems available for this particular problem, and has an acceptable performance when applied to the bigger set of rectangle instances.
Keywords: irregular packing, guillotine cut, beam search

1.3

H4NP, a general heuristic for two-dimensional nesting problems with fixed size containers

Leandro R. Mundim*, Marina Andretta*, José F. Oliveira†, Maria Antónia Carravilla†
** Universidade de São Paulo, São Carlos – SP, Brasil,* † *Universidade do Porto, Portugal*

In this investigation we present H4NP, a new promising heuristic approach to solve the two-dimensional nesting problems with fixed size containers. The H4NP heuristic framework uses a set of placement rules, and in each iteration the framework shuffles the items, chooses randomly a placement rule and builds a solution, which will be saved if it is the best solution found so far, or discarded otherwise.
The state-of-the-art results for different types of problems have been improved during extensive computational experiments with the Identical Item Packing Problem, Placement Problem, Knapsack Problem and Cutting Stock Problem. As far as the authors are aware, the H4NP heuristic is the most effective solution method for two-dimensional nesting problems with fixed size containers.

Keywords: nesting problems, irregular shapes, heuristics, placement rule, fixed size containers

1.4

Algorithms for the 2-D Irregular multiple bin size bin packing problem

Ranga P. Abeysooriya, Julia A. Bennell, Antonio Martinez-Sykora
University of Southampton, United Kingdom

This study investigates the two-dimensional irregular shape packing problem where the pieces may be of any polygonal shape and must be packed into multiple heterogeneous stock sheets. We denote this problem as two-dimensional irregular multiple bin size bin packing problem. To the best of our knowledge, this study is the first to tackle the two-dimensional multiple bin size bin packing problem where the small items are irregular.
As practical examples, the problem extensively applies in manufacturing where pieces are cut from material such as metal, wood, paper and leather industries. The problem involves determining an efficient layout of the pieces and deciding which set of sizes of stock sheet should be used in order to minimize the waste material. We also discuss the solutions for the problem where the number of bins of each bin type is finite. The objective function is to minimize the total area of the bins used to pack all of the pieces while satisfying the no-overlap and containment constraints. We also consider two variation of piece orientation where pieces are restricted to rotate by a finite set of angles or pieces can be freely rotated.
We present a single-pass constructive algorithm that builds a feasible solution by adding pieces sequentially to a packing area defined by a permutation of heterogeneous bins. The problem has a large solution space due to the different combinations of heterogeneous bins and different arrangements of irregular pieces. We design a genetic algorithm (GA) to optimise the order of bins and propose an improvement heuristic approach called Jostle heuristic to optimize the piece order by handling both allocation and placement decisions of pieces together. The solutions are compared with the solutions of packing the same set of pieces in identical size bins. Findings reveal that the proposed algorithms can effectively solve different variants of the problem and finds better utilization of material when compared with packing pieces in identical size bins of each bin size. Accordingly the study reveal that solving two-dimensional irregular multiple bin size bin packing problem is advantageous in terms of saving the stock-sheet material, though it is more complex than solving irregular shapes identical size bin packing problem.

Keywords: heterogeneous bin packing, irregular items packing, jostle algorithm

2.1

JNFP: a robust and open-source Java based nofit polygon generator library

Tony Wauters, Stiaan Uyttersprot, Eline Esprit
KU Leuven, Department of Computer Science, CODeS

Nesting problems are one of the toughest cutting and packing problems. These problems, which are highly relevant for industry, concern the cutting or packing of irregular shapes from a larger one. However, there are two main difficulties hindering the research on these problems. The first difficulty arises from the combinatorial aspect. The problem is NP-complete, which results mainly in the usage of heuristic techniques. The second difficulty, and a large struggle point for researchers developing methods for nesting problems, are the geometrical complications arising from the irregular shapes. An established technique for dealing with these geometrical concerns is the nofit polygon. The nofit polygon defines the overlapping area between two given polygons with fixed orientations. Several methods to obtain these nofit polygons, such as those based on Minkowski sums and the orbiting method, are available in the literature.

Unfortunately, implementing an efficient and robust nofit polygon generator remains a daunting task, especially for researchers lacking the necessary programming skills. Furthermore, no tool or nofit polygon library is publicly available. Therefore, this research proposes a Java NoFit Polygon (JNFP) library. The library provides multiple methods for generating nofit polygons, based on different implementations. Initially, existing methods from the literature are implemented. New methods or method variants can be subsequently added. Basic geometric techniques are shared between the different methods. For example the intersection of two lines. Implemented methods are thoroughly tested on a large set of test cases and compared in terms of both robustness and performance. Note, however, that not all implemented methods will provide the same capabilities, such as dealing with holes, exact-fit, or other such intricacies. Additional tests are added which check these special conditions. An automated selection algorithm is added to the library. This selection algorithm chooses the most appropriate method of generating nofit polygons for any given instance, based on the properties of the input polygons (such as the existence of holes).
JNFP is made public, but also open-source at: `https://github.com/TonyWauters/JNFP`.
Other researchers have the ability to contribute by improving existing implementations or by adding new test cases. Such contributions assist in further developing this library, thereby benefiting every researcher within the cutting and packing field.
Keywords: nofit polygon, geometric algorithms, nesting, open-source library

2.2 A BRKGA based approach for a two-dimensional cutting problem with defects

José Fernando Gonçalves[*], Gerhard Wäscher[†]
[*] *LIAAD, INESC TEC, Faculdade de Economia do Porto, Universidade do Porto,* [†] *Faculty of Economics and Management, Otto-von-Guericke-Universität Magdeburg*

This paper addresses a two-dimensional (2D) non-guillotine cutting problem, where a fixed set of small rectangles has to be cut from a larger stock rectangle with defects so as to maximize the value of the rectangles cut. The algorithm proposed hybridizes a novel placement procedure with a biased random-key genetic algorithm (BRKGA). The approach uses a maximal-space representation to manage the free spaces and the defects. The BRKGA is used to determine the order in which the small rectangles are placed into the large stock rectangle and the novel placement procedure is used to determine the quantity of identical small rectangles to be placed and the maximal space where they should be placed. The approach is tested on a set of benchmark instances taken from the literature and compared with other approaches. The experimental results validate the quality of the solutions and the effectiveness of the proposed algorithm.
Keywords: cutting, packing, two-dimensional, non-guillotine cutting, BRKGA, biased random-key genetic algorithm
Supported by Project "NORTE-01-0145-FEDER-000020" financed by the North Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, and through the European Regional Development Fund (ERDF).

2.3 Equivalent transformations for the d-dimensional Orthogonal Packing Problem

Vadim M. Kartak, Artem V. Ripatti
Bashkir State Pedagogical University named after M. Akmullah, Ufa, Russia

We consider the well-known d-dimensional Orthogonal Packing Problem (OPP-d). Using toolset of conservative scales introduced by Feteke and Schepers we are able to change items' sizes of the initial instance to obtain an equivalent instance with the same solution. We present effective algorithm to build equivalent instances with some specified in advance properties.
The algorithm is based on idea of cut generation and uses LP and ILP solvers to get imtermediate solutions. Our implementation is able to handle instances with $n = 100$ items and integer sizes up to $L = 100000$.
We also consider so-called raster model for OPP-d introduced by Belov, Kartak, Rohling and Scheithauer. It is 0/1 ILP model in which number of variables and constraints depends on total number of raster points over all dimensions. Namely, it contains $O(n \sum_{k=1}^{d} |R_k| + dn^2)$ variables and $O(n^2 \sum_{k=1}^{d} |R_k|)$ constraints, where $|R_k|$ is amount of raster points for dimension k. Using our algorithm we construct equivalent instances with reduced number of raster points. We also present algorithm to build lower bound of minimum possible number of raster points over all equivalent instances. For some instances it proves that it's impossible to reduce number of raster points. Numerical results are presented.

Keywords: orthogonal packing problem, cutting stock problem, conservative scale, equivalence of instances, raster points, raster model, linear programming

2.4

Dynamic pricing in the ferry industry

A. Martinez-Sykora, C. Bayliss, C.Currie, M. So, J.A. Bennell
University of Southampton

In this paper we present a dynamic pricing model on the ferry industry in which efficient packing algorithms are used to fit more vehicles in the ferry, leading to better expected revenues.
The origins of the revenue management (RM) lie in the airline industry. In 1997 it was shown the potential of this market when RM were introduced with a profit of 60$ millions in the year 1984. RM practices generated 1,4 billion in additional revenues at American Airlines in the three year period starting from 1988. One of the consequences of such potential is that most of the world's major air carriers and many smaller airlines have some level of revenue management capability. The main issue when applying the dynamic programming models used in the airline industry and in the ferry industry is how to measure the space left in the ferry, whilst avoiding overbooking. In the airline industry the number of sales is determined by the number of seats, however, in the ferry industry the number of vehicles which could fit in the ferry depends on the layout used in the ferry. Furthermore, a better placement of the vehicles allows either more vehicles or bigger vehicles to be placed and, therefore, there is a higher chance to increase the expected revenues.
In order to solve the pricing problem, in which the expected revenues are maximized, we solve a dynamic programming formulation in which the number of states (layouts), i.e. the number of vehicle mixes that can be accommodated at each time period in the selling season is calculated from packing algorithms.
We propose two different approaches to place the vehicles in the ferry. In a first approach the decks are divided into lanes, and each lane has a known length, width and height, leading to a one dimensional heterogeneous bin packing problem. In the second approach the number of lanes and their widths are not given, so they should be decided by the packing algorithms, leading to a two dimensional rectangular packing problem.
In order to solve the pricing model more efficiently we need to find all the solutions in the Pareto frontier, where the number of vehicles placed in the ferry of each type is a single objective. We use an iterative procedure to find all the solutions. In order to decided whether a set of vehicles fits on the ferry or do not fit, we explore fast constructive heuristics like the minimum length placement heuristic (bottom left heuristic) and first fit decreasing algorithms. In addition, we propose an IP model to solve the packing problem to optimality, which is capable of finding all of the feasible solutions with a reasonable computational effort. We extend this IP model to case where the lane dimensions are real variables.
We present some computational results on instances generated based on real data. The results shows that the expected revenues increases when the packing is solved more efficiently, and the exact algorithm is capable to solve instances with up to 5 vehicles types, 4x50 meter lanes and a 100 price types.
Keywords: dynamic pricing, 1d multiple bin size bin packing, 2d rectangular bin packing

3.1

A best fit decreasing algorithm for the three dimensional bin packing problem with transportation constraints

C. Paquay, S. Limbourg, M. Schyns
University of Liege, HEC Management School

In this work, we consider the problem of selecting containers in order to pack a set of cuboid boxes while minimizing the unused space inside the selected containers. The set of boxes is highly heterogeneous while there are few types of containers to select. In the literature, this problem is called a three dimensional Multiple Bin Size Bin Packing Problem (MBSBPP).
As it is the case for the packing problems, the pattern has to satisfy geometry constraints: the items cannot overlap and have to lie entirely inside the bins. The richness of our application is to deal with additional and common constraints: the bin weight capacity, the rotations of the boxes, the stability and the fragility of the boxes and the last but not the least, the uniformity of the weight distribution inside the bins. In addition to this, in the context of air transportation, bins are called Unit Load Devices (ULD). A ULD is an assembly of components consisting of a container or of a pallet covered with a net, so as to provide standardised size units for individual pieces of baggage or cargo, and to allow for rapid loading and unloading. ULDs may have specific shapes to fit inside aircraft.
This specific problem has been formulated as a MIP and then studied through MIP-based constructive heuristics. The aim of the present work is to find good initial solutions in short computational times. We develop here a best fit decreasing algorithm (BFD) designed for this specific problem as it showed interesting results in terms of

worst-case performance ratio for the one dimensional bin-packing problem. As a reminder, the BFD first sorts the list of items by non increasing size and then considers one item after another. Then, it assigns an item to the feasible bin (if any) having the smallest residual capacity. If there is no such bin, then a new one is created. However, the adaptation of this algorithm is far from trivial: several rules for sorting the items and the bins exist and placing a box in a bin can also be achieved in different ways. In particular, the choice of placement points is a major challenge in multi-dimensional packing or cutting problems. Indeed, the space utilization and the solution quality are highly influenced by the item-positioning rule. This issue is particularly crucial and difficult to manage for three dimensional situations.
We based our algorithm on the concept of Extreme Point (EP) from Crainic T.G., Perboli G. and Tadei R. (2008). The EPs represent the interesting possible positions to accommodate items. We modify this concept as well as the choices of sorting rules to take into account the different constraints of our problem. The algorithm is tested on real data sets and the results are compared to those obtained with a traditional branch-and-bound resolution.
Keywords: bin packing, best fit decreasing algorithms, extreme points
This project is partially funded by the Interuniversity Attraction Poles Programme initiated by the Belgian Science Policy Office (grant P7/36).

3.2
Generating real-world-like problem instances

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In this talk, we introduce a highly configurable problem generator for container loading problems (CLP). Our work focuses on air cargo where a lot of constraints like load-bearing, item compatibilities and positioning constraints arise in practice. To the best of our knowledge there exist no publicly available problem instances dealing with this type of CLP yet. We attribute this to the fact that many companies dealing with real loading problems are reluctant to share authentic data or data of their customers respectively. But, according to the state-of-the-art review on container loading constraints by Bortfeldt and Wäscher (2013) such challenging test problems (or problem generators) are needed to evaluate new algorithms.
Our idea is to share synthetic but still close to reality instances. Therefore, we analyze the real-world problem, in our case the CLP in air cargo, and extract its key characteristics. With it we configure the problem generator and run it to create a set of instances. The instances and generator configuration can then be exchanged between researchers even if the original data cannot for confidentiality reasons. The generator configuration is especially interesting to create further instances (e.g. larger ones) with similar characterics.
We present the current state of the generator and the results of our study on air cargo CLP characteristics in practice. Furthermore, we analyse existing benchmark instances in the same way to determine their applicability to evaluate algorithms for CLP in air cargo.
Keywords: air cargo, problem generator, container loading

3.3
A review and model proposal for the balance and weight limit constraints on road transport

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The Container Loading Problem is a combinatorial optimization problem, which appears in the transportation industry, and has a high economical, safety and environmental impact. Generally, in the Container Loading Problem a set of boxes must be packed orthogonally inside a container, such that boxes do not overlap and lie entirely within the orthogonally, while maximizing the space utilization. In this problem, the way cargo is arranged inside the container is very influenced by the way cargo is arranged inside the container.
In this work we address two of the most practical relevant constraints within the Container Loading Problem, the balance and weight constraints and explore the interrelation between them. These constraints are frequently addressed separately, even though they are intimately related. The balance constraint is usually enforced by guaranteeing the centre of gravity of the cargo being located within a given gap of the geometric centre of the container. The weight limit constraints is usually enforced as a hard constraint where the sum of the weight of the boxes must not exceed the maximum weight allowed inside the container.
We start by reviewing the existing literature on Container Loading Problem papers that address these constraints and compare it to the way balance and weight are actually present in the road transport mode, giving a particular focus on the influence of the standards and legislation that regulate the sector. Finally we present a more realistic model of these constraints to incorporate into a Multi Population Biased Random Key Genetic Algorithm.
Keywords: container loading, balance, weight limit

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3.4

Analysis of test instances for Container Loading Problems

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Generally in Container Loading Problems (CLP), a set of parallelepiped boxes must be packed inside a container, such that boxes do not overlap and lie entirely within the container. Two different objectives can be considered: the output value maximization and the input value minimization. In the case of the output value maximization the goal is to assign a selection of items to the container with the maximum value. On the other hand, in the case of input value minimization, all the boxes must be assigned to the minimum number of containers. The CLP has been extensively studied in the literature, however the applicability of existing algorithms is limited in many real problems of the transportation industry. The inadequacy of the existing approaches is mainly related with the over simplification of some practical constraints. Two of the most relevant practical constraints in the transportation industry are the balance and weight constraints.

In this work an analysis of the existing test instances used by the algorithms for CLP considering balance and weight constraints is presented. Besides, we will try to outline a problem generator which can be able to generate problems instances that characterize realistic constraints.

Keywords: container loading, problem instances, realistic constraints

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4.1

Analysis of solution representation for the rectangle packing problem

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The rectangle packing problem is one of the simple and most investigated problems. We discuss how to represent solutions for the rectangle packing problem. (We mainly consider problems to place all the given small items in one large rectangle with variable size.) A simple method is representing a solution as a layout itself; constructing a layout directly and/or searching for better layouts by moving rectangles in a layout. Another popular representation of a solution is a permutation of rectangles. For a given permutation of rectangles and a placement rule such as the bottom left and the best fit strategies, a layout of rectangles based on the permutation can be computed. There are many state of the art algorithms with this solution representation; improvements of such algorithms are credited to better heuristic rules, enhancements of computation environment, and inclusions of instance specific features.

There are many other methods to represent solutions (in other words, coding schemes) mainly proposed by researchers belonging to the circuit design societies. One of the representative methods in this category is Sequence-Pair, which uses two permutations of rectangles to represent a solution. We study characteristics of this and other related solution representations for the problem. We intend to establish some principles of the strengths and weaknesses and gain better understanding of how these solution representations impact the quality of solutions and the effectiveness of the search. We also discuss solution representations for the rectangle packing problem with additional constraints and three dimensional packing problems.

Keywords: rectangle packing, solution representation, coding scheme, heuristics, local search

4.2

Solving methods for a two-dimensional knapsack problem

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We compare different exact methods for solving a two-dimensional knapsack problem with guillotine constraints. The problem input consists of a large plate of width W and height H, and a set of items I, each of them having a

width w_i, a height h_i, a profit p_i and available d_i times. The objective is to cut a subset of items from the plate such that the sum of their profits is maximized. In guillotine cutting problems, each cut is performed in straight line from one side of the bin to the opposite. We study the 4-stage version of the problem, where each item has to be cut in at most 4 cuts. We also consider that cut lengths are restricted (*i.e.* they have to be equal to the height or width of an item). Item rotation is permitted.
If bound constraints are relaxed, our problem can be solved by dynamic programming (see [1]). Such a dynamic program can be reformulated as a max-cost flow problem in a hypergraph (see [3]). Each vertex corresponds with a constraint, while each hyperarc corresponds with a decision variable. Our contribution is a comparison of several methods to manage efficiently the item upper bounds. We first compared several preprocessing methods to reduce the size of the formulation (dominance rules, arc filtering). We also implemented two methods for solving the resulting formulation: directly entering the MIP formulation, or solving the dynamic program, handling the bounds with a label setting algorithm. We compare both methods with the best method from the literature [2].
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Keywords: two-dimensional knapsack, extended formulation, hypergraph, flow model

4.3

Creating Worst-Case Instances for Upper and Lower Bounds of the Two-Dimensional Strip Packing Problem

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We present a new approach to create instances with high absolute worst-case performance ratio of common heuristics for the two-dimensional Strip Packing Problem. The idea of this new approach is to optimize the length and the width of all items regarding the absolute worst case performance ratio of the heuristic. Therefore, we model the solution obtained by the heuristic as a solution of an ILP problem and merge this model with the Padberg-model of the two-dimensional Strip Packing Problem. The merged model maximizes the absolute worst-case performance ratio of the heuristic. We introduce this new model for the Next-Fit Decreasing-Height, the First-Fit Decreasing-Height and the Best-Fit Decreasing-Height heuristic. Furthermore, we provide an opportunity to use this idea to create worst-case instances for lower bounds. For this model we have to create constraints, which ensure that a certain pattern (structure of arrangements) is an optimal solution to the Strip Packing Problem. We show how to create such constraints and introduce this model for the horizontal bar relaxation and the contiguous horizontal bar relaxation.
Keywords: cutting and packing, strip packing problem, heuristics, performance bounds

4.4

A new heuristic for the rectangular two-dimensional strip packing problem

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Cutting and Packing (C&P) problems have been extensively studied in the last decades, mainly due to its computational complexity (almost all NP-hard) and numerous real-world applications.
In this work it is intended to determine the best way to place a set of small rectangular items into a large object, with a predefined width and infinite height, minimizing the total height used. This specific C&P application is known as Two-Dimensional Strip Packing Problem (2D-SPP). The challenge is to minimize the height of the object necessary to arrange all items, satisfying the physical and structural constraints.
The items and the object have rectangular shape, and should be orthogonally positioned in the empty spaces available in the object, without any overlap and no items rotation. Regarding the types of cuts that can be performed, it is considered the non-guillotine version.
In the proposed solution method, two different constructive heuristics are used: the Fast layer-based Heuristic (FH) and the Bottom-Left-Fill (BLF). The FH searches for the best relation between spaces and items available, at each positioning step, according to a scoring system. Highest scores define that a smaller number of edges have been generated after the positioning of the item in the selected space. In the BLF the remaining items are placed as far down and to the left as possible.

The first complete solution is generated with the combination of FH and BLF, and the selection of the constructive heuristic strategy is based on the number of items that has been positioned in the object. This approach does not need a pre-tuning of the parameters and was developed with the objective of obtaining the best fit between the available spaces and the items to be positioned.
To improve the first complete solution found, we adopted a Local Search Metaheuristic, due to its capacity to quickly find neighbour solutions in the feasible search space, changing randomly the initial order of the items.
Computational experiments were conducted on a set of instances from the literature and will be presented.
Keywords: strip packing problems, heuristics, local search
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5.1
A savings heuristic for the 3L-VRP with backhauls and time windows

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A vehicle routing problem (VRP) with three-dimensional loading constraints with backhauls and time windows is presented. That is, sets of different three-dimensional items have to be delivered to customers. The problem combines the VRP with the container loading problem where packing constraints such as vertical orientation, support requirements or LIFO constraints have to be considered. Furthermore, we consider time windows and different backhaul variants such as clustered backhauls, i.e. within a tour all linehaul customers must be visited before the backhaul customers are approached, or mixed backhauls where linehaul and backhaul customers can be visited in mixed sequences.
For solving the problem a savings heuristic was implemented and adjusted to the different backhaul variants and tested for newly generated instances. Within this procedure different packing heuristics, like the deepest-bottom-left-fill or touching-perimeter heuristic, are applied and compared. The corresponding results will be presented.
Keywords: vehicle routing, packing, backhauls, time windows

5.2
Guide & Observe for the ESICUP 2015 Challenge problem: an analysis of objective functions

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The 3D Multi-Container Loading Problem has been studied by several teams of researchers in the event of the ESICUP 2015 Challenge, and has proven to be highly relevant in practice. The main aim is to organize items in stacks, which are subsequently packed in containers. Transportation companies face container loading problems every day, and the quality of the solutions highly impacts the cost of transportation.
The main objective of the present problem is to reduce the total container volume. Although this objective accurately represents the transportation costs, it does not provide much guidance to a local-search based approach. The objective function only changes whenever an entire bin is removed or added, making it harder for the algorithm to detect improvements to the stacks or the load arrangement. The use of alternative objective functions could help to guide the search procedure towards better solutions by providing a less deceptive search landscape.
Several alternative objective functions are proposed. A Guide & Observe strategy is applied, using an alternative objective function to guide the search procedure and the original objective function to observe the solutions found. Experiments are conducted on instances from the ESICUP 2015 Challenge Problem. The characteristics of the new search landscape are studied. The impact of the alternative objective functions on the local search performance is evaluated, and the correlation between the new and original objectives is analyzed.
Keywords: 3D container loading, objective functions, guide & observe

5.3
Solving the stowage slot planning problem with GRASP

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The stowage planning problem, in which a plan is developed for the position of the containers in a ship, is, according to the state-of-the-art, most efficiently solved in two phases. In the first phase, Master Planning, groups of containers are assigned to locations in the ship. In the second phase, Slot Planning, the exact position of each container is determined.
We address the slot planning phase, in which the containers assigned to a container ship location have to be stowed, satisfying many conditions related to the way in which containers have to be stacked, the weight distribution, and the specific conditions regulating the containers with dangerous products. We can see this problem as a packing problem where we have to pack a set of items (containers) into a set of bins (stacks) that forms a location of the ship. The main objective is to pack as many containers as possible, all the assigned containers if they feasibly fit into the location, and the secondary objective is to minimize the number of unproductive moves of containers that have to be removed just to get access to other containers below them.
In order to study the structure of the problem, we have developed an integer linear model. In order to efficiently solve problems of realistic size, we have developed a GRASP algorithm which includes two constructive methods, several randomization strategies, and several improvement moves. The algorithms have been tested on both a set of real-world and custom generated instances. The results show that the GRASP algorithm obtains good results in a wide range of problems.
Keywords: container vessel stowage planning, slot planning, integer programming, heuristic algorithms, GRASP

5.4

Models and algorithms for a multi-port container ship stowage problem

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The stowage planning problem consists in developing a plan for the position of the containers in a ship. This plan has to satisfy high-level constraints, related to the stability of the ship, as well as low-level constraints related to the way in which containers have to be stacked, the weight distribution, and the specific conditions regulating the containers with dangerous products. The main objective is to pack as many containers as possible, all the assigned containers if they feasibly fit into the ship. A secondary, but very important secondary objective is to minimize the number of unproductive moves in the loading/unloading operations. Unproductive moves appear when at one port some containers going to later ports have to be unloaded to get access to containers that must be unloaded at that port.
In this paper we study the simplified, purely combinatorial problem in which stability, weight, and other specific conditions are not considered and the problem consists in determining the position of the containers loaded at each port so as to minimize the number of unproductive moves necessary to unload the containers at their port of discharge. It can be seen as a multi-drop loading problem in which removing some containers to unload others may be unavoidable, but the number of these moves is minimized.
Several integer models as well as heuristic procedures have been proposed for this problem. We have developed a new integer linear model, reducing the number of variables and proposing several sets of valid inequalities that enhance the model and improve its performance. We have also designed heuristic procedures in order to obtain good quality solutions for large instances that cannot be solved by exact methods.
An extensive computational study, using instances of different sizes and characteristics, show the efficiency of the proposed models and algorithms.
Keywords: container vessel stowage planning, integer models, heuristics

6.1

Heuristics for the Bitmap Shape Packing Problem: Efficient Implementations and Placement Strategies

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The bitmap shape packing problem involves packing a set of arbitrarily shaped polygons represented in bitmap format, called bitmap shapes, into a larger rectangular container without overlap. The objective is to minimize the height of the container. This problem is important for many industrial applications such as garment industry, paper cutting and VLSI design. It is among the classical packing problems and is known to be NP-hard.
The complex geometry of bitmap shapes and the large amount of data to be processed make it difficult to check for overlaps. As a consequence, most of the algorithms in the literature consider only small-scale instances. In this study, we first propose methods for checking for overlaps among objects and then generalize the efficient implementations of two construction algorithms, the bottom-left and the best-fit algorithms, from the case of the rectilinear block packing problem to the case of the bitmap shape packing problem.

The main strategy of these algorithms is the bottom-left strategy. In this strategy, starting from an empty layout, objects are packed into the container one by one at the leftmost position as low as possible.
To improve the quality of the solutions, we also propose some modified strategies to determine the position to place objects by using new evaluation criteria based on the shape of the new object and the current packing layout. The computational results for a series of instances that are generated from well-known benchmark instances show that the proposed algorithms obtain good solutions in short time and are especially effective for large-scale instances.
Keywords: bitmap shape, strip packing, overlapping check, efficient implementation, placement strategies

6.2

A new global optimization method based on clustering and parabolic approximation for the shoe nesting on leather

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Leather is a flexible material used in a variety of industries such as textile, clothing, furniture and automotive. Its production process comprehends different stages until the final product reaches the customer and undoubtedly, the most important stage is the cutting process. Through the cutting stage, small pieces are obtained from a larger object following a predefined packing placement. The quality of the packing placement is primordial, since an optimized placement can reduce the leather wastage during serial production. In this study, a new optimization method that is unconstrained Global Optimization method Based on Clustering and Parabolic Approximation (GOBC-PA) has been used for the Leather Nesting Problem (LNP). The LNP can be categorized as a two dimensional residual cutting stock problem according to the typology of Wäscher, Haußner, and Schumann. Therefore, we adapted this method to shoe pattern nesting on the leather. GOBC-PA is an iterative algorithm. In each step, the data are clustered and the cluster centers denote the local optimums. These centers are adapted with locally fitted parabolas instead of gradient descent. Therefore, the convergence rate of GOBC- PA is better than other heuristic methods. The GOBC-PA gives good results in acceptable ratios when the method is tested with the benchmark datasets. The most important stage of nesting problems is cost calculation because of it directly affects the efficiency and speed of the algorithm. The raster method is much more suitable than mathematical expressions or direct geometry according to cost function evaluation. As a result, the raster method was preferred in this study. Distance transform method was also used to minimize and to simplify the mathematical procedures. The GOBC-PA can reach to optimal placements of patterns in a few steps and short time. The resolution of the raster directly influences the speed of the algorithm. Different resolutions were tried and the optimal resolutions have been found for shoe pattern nesting. In experimental studies, the GOBC-PA method was tested with different shoe patterns and leather raw materials that have irregular regions or different sizes. The GOBC-PA was also compared with Particle Swarm Optimization (PSO). The obtained results denoted that the GOBC-PA is more successful and faster than PSO and ABC (Artificial Bee Colony).
Keywords: nesting, leather cutting, irregular packing, shoe making, optimization

6.3

Raster Approach to the Nesting Problem

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One of the most complex problems in the area of 2-dimensional cutting & packing are irregular packing problems, in which the geometry of items are often more complex. They consist of placing a set of items, whose geometry are often represented by simple polygons, into one container such that there is no overlap between items and the utility rate of the container is maximized. In this work, the irregular strip packing problem, in which the container has an variable length, is investigated. A raster heuristic is employed to limit the placement possibilities through the adoption of a rectangular grid, and a full search is performed using the raster penetration map to determine the new position of an item. Moreover, some techniques are employed to speed up the calculations involved. Tests were performed using benchmark cases, whose results were competitive, and using simple dotted board model cases. In the latter cases, some optimum solutions were already determined in the literature and, in such instances, the proposed solution was always capable of producing an optimum layout.
Keywords: no-fit polygon, overlap evaluation, separation and compaction, irregular packing problem

6.4

Voxel based heuristics for 3D irregular packing

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Three dimensional irregular strip packing consists in placing a collection of three dimensional objects in a container of fixed width and length while minimising its height. This problem has not been widely studied in the literature due to its geometric and computational complexity. In this paper we develop a heuristic algorithm that can find efficient packing layouts with low computational effort. Key to developing the solution approach are tools to efficiently process the geometry. The most commonly used representations in packing contexts are the triangle mesh boundary representations and, to smaller extent, Φ–objects. Despite their flexibility and accuracy, mesh representations have time consuming intersection tests; on the other hand Φ–functions can be very difficult to obtain for complex Φ–objects. There is a third approach which consists in discretising the space and representing the objects by voxels, a natural extension of the 2D pixel / raster method. Voxels are small cube volumes that are joined together to represent arbitrary shapes efficiently.

In this work, we approximate arbitrary solid objects, which may be convex or non convex, with a fixed orientation, by voxels. Our packing application consists in placing a collection of items in a container of fixed width and length while minimising its height. For this, we develop a heuristic algorithm which is based on a bottom-left-back strategy. The algorithm examines different piece order sequences and slides the objects from a top-right-front position to a bottom-left-back placement iteratively, in order to minimise the container height. The usage of voxels allows for very quick intersection tests between the items, which in turn reflects in competitive packing times and robust results.

Preliminary results show that the voxel-based representation is effective in dealing efficiently with the interaction of complex 3D objects, capturing the most relevant properties of the shapes. Reducing the computational effort of the intersection tests allows us to use the algorithm as the basis for more sophisticated meta-heuristics and can provide upper bounds for exact methods. Furthermore, the sliding nature of the algorithm ensures that the solutions are realistic and can be physically constructed, i.e., no objects are placed in feasible but physically unobtainable positions, such as inside of hollow objects.

Keywords: 3d irregular packing, open dimension problem, voxel, heuristics

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Notes

Map

Google maps link: here