12th ESICUP Meeting

Portsmouth, UK,
March 29-31, 2015

Sponsors
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Organised by:

ESICUP – EURO Special Interest Group on Cutting and Packing
University of Portsmouth
University of Southampton

Supported by:

The OR Society, OPTRAK and INESC TEC
Challenge ESICUP 2015 supported by Renault and organised by the Operations Research team of the Bordeaux University
Welcome

Dear Friends,

Welcome to the 12th 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) and this 12th meeting is now held in Portsmouth (United Kingdom).

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

We are delighted to host the first ESICUP-Challenge sponsored by the automotive maker RENAULT and with the cooperation of the Operations Research team of the Bordeaux University. The challenge focuses on container loading for logistics platforms. We look forward to hearing from the contestants and the presentation of the two prizes totalling 14,000 euros.

The city of Portsmouth, with its rich historic background, and the University of Portsmouth, as one of the top 10 modern universities in the United Kingdom, provide an excellent platform for making this meeting a remarkable one.

Portsmouth is the second largest city in the ceremonial county of Hampshire on the south coast of England. Portsmouth is notable for being the United Kingdom’s only island city; it is mainly on Portsea Island. It is situated 64 miles (103 km) south west of London and 19 miles (31 km) south east of Southampton. As a significant naval port for centuries, Portsmouth is home to the world’s oldest dry dock still in use and also home to some famous ships, including HMS Warrior, the Tudor carrack Mary Rose and Lord Nelson’s flagship, HMS Victory. We hope that you will be able to take advantage of the organised trip to the historic dockyard where you can visit these magnificent ships. You can also visit The Spinnaker Tower, a striking recent addition to the city’s skyline. It can be found in the redeveloped former HMS Vernon, formerly a shore establishment or ‘stone frigate’ of the Royal Navy, now an area of retail outlets, restaurants, clubs and bars now known as Gunwharf Quays.

University of Portsmouth (UoP) was previously known as Portsmouth Polytechnic until 1992, when it was granted university status through the Further and Higher Education Act 1992. The University of Portsmouth was ranked in the top 400 universities in the world in the most recent Times Higher Education World University Rankings published in 2013. The independent rankings place Portsmouth in the top two per cent of universities worldwide and among the best in Europe. Research at the University of Portsmouth is rated world-leading in the latest survey of research quality in UK universities.

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 Portsmouth!

Julia Bennel
University of Southampton
Program Chair

Xiang Song
University of Portsmouth
Local Organizer
Information for Conference Participants

MEETING VENUE
The 12nd ESICUP Meeting will be held at Richmond Building in the University of Portsmouth. The institute is located close to city centre and two main train stations in Portsmouth - “Portsmouth & Southsea” and “Portsmouth Harbour” (5 minutes by walk from the train station).

Address:
Richmond Building, Portland Street, Portsmouth, PO1 3DE
REGISTRATION
The registration desk will be located at the entrance (ground floor) of the Richmond Building, where you will collect your name badge and registration pack for the event. Registration will be open from 8.30am to 10.30am, March 30-31, 2015.

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

NOTES ON PRESENTATION
- **Equipment**
  The conference room is equipped with an overhead projector and a laptop computer will be provided. We suggest that you bring your own computer and/or transparencies as a backup.

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

INTERNET
Wireless access is available in all the University’s buildings and can be accessed using one of the following usernames and passwords:

- User: ta009809 Pass: j9y7wf Name: song xiang
- User: ta009810 Pass: 0gqcb3 Name: xiang song

The following are the general settings to connect to the University’s `eduroam` wireless network:

- Wireless network name (SSID) = `eduroam`
- Authentication type/EAP method = `PEAP`
- Authentication protocol = `MSCHAPv2`
- User login/identity = your given username and password
- Anonymous identity = leave blank

For further information: [http://ithelp.port.ac.uk/questions/194/Wireless+connection+guide](http://ithelp.port.ac.uk/questions/194/Wireless+connection+guide)

HEALTH AND SAFETY
- **Fire alarms** – All fire alarms in the University buildings are tested weekly. Fire alarms are located on each floor of each building.
- **Fire exits** – Fire exits are clearly labelled throughout each building.
- **Fire assembly point** – Open area outside of the Richmond Building.

TOILETS (RICHMOND BUILDING)
- **Ladies** – Ground floor and 2nd floor
- **Gents** – Ground floor and 1st floor
- **Disabled** – Ground floor and 1st floor

SMOKING
Smoking is prohibited in all University's buildings, but there are designated smoking areas outside.

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

LUNCHES AND COFFEE BREAKS
- Two buffet lunches in **Dennis Sciama Building** (student area), see map on previous page.
- Coffee breaks will be held in the **Richmond Building** (atrium).
GET-TOGETHER EVENING
Takes place on Wednesday 29th March, from 17:30 to 20:00, at The Old Customs House, Address: Vernon Building, Gunwharf Quays, Portsmouth, Hampshire PO1 3TY (see map in last pages).
Note: refreshments, snacks and meals available on a pay-yourself basis.

CONFERENCE DINNER
Takes place at Restaurant Strada on Monday 30th March, from 19:00. Address: R2-R3 City Quay, Gunwharf Quays, Portsmouth Harbour, Portsmouth PO1 3TW (see map in last pages).
Notes: three courses (starter, main and dessert), drink included

EXCURSION TO SPINNAKER TOWER AND PORTSMOUTH HISTORIC DOCKYARD
The excursion to Spinnaker Tower and Portsmouth Historic Dockyard on Tuesday March 31st from 14:00.
Walking together to the Portsmouth Historic Dockyard and visit both the Spinnaker Tower and a ship in the Portsmouth Historic Dockyard
Note: £18.50/person

CITY AND MOVING AROUND

• About Portsmouth
Portsmouth is the second largest city in the ceremonial county of Hampshire on the south coast of England. Portsmouth is notable for being the United Kingdom’s only island city; it is mainly on Portsea Island. It is situated 64 miles (103 km) south west of London and 19 miles (31 km) south east of Southampton.

As a significant naval port for centuries, Portsmouth is home to the world’s oldest dry dock still in use and also home to some famous ships, including HMS Warrior, the Tudor carrack Mary Rose and Lord Nelson’s flagship, HMS Victory. Although smaller than in its heyday, the naval base remains a major dockyard and base for the Royal Navy and Royal Marine Commandos whose Headquarters resides there. There is also a thriving commercial cruise ship and ferry port serving destinations on the continent for freight and passenger traffic. The City of Portsmouth and Portsmouth Football Club are both nicknamed Pompey.

The Spinnaker Tower is a striking recent addition to the city’s skyline. It can be found in the redeveloped former HMS Vernon, formerly a shore establishment or ‘stone frigate’ of the Royal Navy, now an area of retail outlets, restaurants, clubs and bars now known as Gunwharf Quays.
For more information, please visit http://www.visitportsmouth.co.uk/.

• Getting There (http://www.port.ac.uk/maps-and-directions/#directions)
  – By Train
    London Waterloo (1hr 30mins) or London Victoria (2hrs 10mins)
    Bristol (2hrs) and South Wales (3hrs 15mins)
    Frequent South Coast services to Southampton, Bournemouth and Brighton

Portsmouth has two main stations, “Portsmouth & Southsea” and “Portsmouth Harbour”, which are within walking distance from all buildings on the Guildhall Campus. For details of train services, please visit: http://www.nationalrail.co.uk

  – By Air
    Heathrow Airport (1hr 30 mins by road via A3(M)/M25) for all international connections
    Gatwick Airport (1hr 30 mins by road, 1hr 36 mins by rail) for international connections
    Southampton International Airport (30 mins by road via M275/M27) for regular flights to Paris, Cherbourg, the Channel Islands, Belfast, Glasgow

  – By Car
    London (2hrs via A3(M))
    M25 London orbital (1hr via A3(M))
    Bristol (2hrs via M27/A36) onwards to South Wales
    Birmingham (3hrs via A34/M40)

Car parking – We would encourage you to use public transport where possible. Pay & Display parking is available on Hampshire Terrace (PO1 2QF), Cambridge Road (PO1 2EF), Gunwharf Quays Car Park (PO1 3TZ), or Stanhope Road Car Park (PO1 1DU). Most of them cost £10 max for parking all day.
Parking is restricted at the University of Portsmouth (UoP) car parks, unless you have a valid UoP parking permit. Failure to display a UoP parking permit will result in a Parking Charge Notice (PCN), payable to Portsmouth City Council. If you require disabled access parking, please email corl@port.ac.uk.

- Moving around (http://www.port.ac.uk/maps-and-directions/#transport)
  - By Bus
    Stage Coach No. 23, 21, 700, 20 frequently visit the bus stop near the University of Portsmouth. Get off on Queen street between Portsmouth City Centre and Portsmouth Harbour. Bus route of the Stage Coach Network can be found on their website: http://www.stagecoachbus.com/uploads/portsmth_havnt_haylngntwkmap.pdf
  - By Taxi
    Aqua Cars: Tel. +44 (0)23 9265 4321
    City Wide: Tel. +44 (0)23 9283 3333
    Streamline: Tel. +44 (0)23 9281 1111
Program Overview

- **Session 5**
- **Session 4**
- **ESICUP-Renault Challenge**
- **Lunch**
- **Closing Session**
- **Excursion to Spinnaker Tower and Portsmouth Historic Dockyard**
- **Session 3**
- **Session 2**
- **Coffee break**
- **Coffee break**
- **Session 1**
- **Opening Session**
- **Registration**
- **Coffee break**
- **Lunch**
- **Session 4 ESICUP-Renault Challenge**
- **Get-together**
- **Conf. Dinner**
- **Session 3**
- **Session 2**
- **Coffee break**
- **Session 1**
- **Opening Session**
- **Registration**
- **Excursion to Spinnaker Tower and Portsmouth Historic Dockyard**
- **Session 4 ESICUP-Renault Challenge**
- **Get-together**
- **Conf. Dinner**

Portsmouth, UK, March 29-31, 2015
Scientific Program Schedule

Monday March 30th
9:00 – 9:15
Opening Session

Welcome Address

9:15 – 10:30
Session 1  Chair: Julia Bennell

1.1 – Container Loading Problem: realistic problem instances are needed
   Elsa Silva, José F. Oliveira, António G. Ramos

1.2 – Efficient management of heterogeneous helicopter fleets
   Carlos Lamas-Fernandez, Julia A. Bennell, Antonio Martinez-Sykora

1.3 – GPU sequence based heuristic for the Nesting problem
   A. Miguel Gomes, Pedro Rocha, Rui Rodrigues

11:00 – 12:30
Session 2  Chair: Ramon Alvarez-Valdes

2.1 – A Tabu Search Algorithm for a Two-Objective One-Dimensional Cutting Stock Problem
   Antonio Martinez-Sykora, Chris Potts, Chris Hantang, Robert Donnelly, Constantine Goulmis

2.2 – A biased random-key genetic algorithm for the unconstrained unequal area facility layout problem
   José Fernando Gonçalves

2.3 – A Join & Cut Problem
   Constantine Goulmis, Denis Jaubert

2.4 – Bin Packing with Due Dates
   Claudio Arbib, Fabrizio Marinelli

14:00 – 15:30
Session 3  Chair: Xiang Song

3.1 – Upper Bounds for Heuristic Approaches to the three-dimensional Strip Packing Problem
   Torsten Buchwald, Guntram Scheithauer

3.2 – Extended formulations for an exact 4-stage restricted guillotine bin packing problem with rotation
   Quentin Viaud, François Clautiaux, Ruslan Sadykov, François Vanderbeck

3.3 – A Scalable Approach for Large-Scale Instances of the K-Staged Two-Dimensional Cutting Stock Problem
   with Variable Sheet Size
   Frederico Dubberger, Günther R. Raidl

3.4 – New inequalities for 1D relaxations of the 2D rectangular strip packing problem
   Isabel Friedow, Guntram Scheithauer

Portsmouth, UK, March 29-31, 2015
16:00 – 17:00

ESICUP - Renault Container Loading Challenge (2015)  
Chair: François Clautiaux

4.1 – A Heuristic Algorithm for the Container Loading Problem of Challenge Renault/ESICUP
H. Iwasawa, Y. Hu, H. Hashimoto, S. Imahori, M. Yagiura

4.2 – A randomized multi-start algorithm for the Container Loading Problem of Renault
M.T. Alonso, R. Alvarez-Valdes, J. F. Correcher, F. Parreño

4.3 – A heuristic approach to the ESICUP 2015 Challenge Container Loading Problem
Tâlio A. M. Toffolo, Tony Wauters, Eline Esprit, Greet Vanden Berghe

4.4 – Genetic approach to ESICUP Renault Container Loading Challenge 2015
Aliaksei Kolesau, Pavel Irzhauiski, Aliaksandr Nekrashevich, Henadzi Klimuk, Pavel Shaftsidevich, Vladimir Kotov

Tuesday March 31th

9:00 – 10:30

Session 5  
Chair: A. Miguel Gomes

5.1 – A hole filling heuristic for the Nesting problem with continuous rotations
Pedro Rocha, Rui Rodrigues, A. Miguel Gomes, Marina Andretta, Franklina M. B. Toledo

5.2 – An investigation of constructive heuristics in 2D-irregular shaped strip packing problems with free rotation
Ranga P. Abeysooriya, Julia A. Bennell, Antonio Martinez-Sykora

5.3 – A robust model for the irregular strip packing problem
Luiz Henrique Cherri, Leandro Resende Mundim, Maria Antónia Caravilla, José Fernando Oliveira, Marina Andretta, Franklina Maria Bragon Toledo

5.4 – A Residual-Space-Maximized Algorithm for Nesting Problems
Lujie Chen, Yanchao Wang

11:00 – 12:30

Session 6  
Chair: José Fernando Oliveira

6.1 – Several constructive heuristics for the three dimensional Multiple Bin Size Bin Packing Problem with air transportation constraints
C. Paquay, S. Limbourg, J.F. Oliveira, M. Schyns

6.2 – Routing problems with 3D loading constraints and reloading effort
Andreas Bortfeldt, Dirk Männel

6.3 – A decomposition-based approach to the safe vehicle routing problem with sequential loading
Eline Esprit, Greet Vanden Berghe

6.4 – Dynamic stability metrics for the Container Loading Problem
António Galrão Ramos, José F. Oliveira, José F. Gonçalves, Manuel P. Lopes

12:30 – 12:40

Closing Session

Closing Notes

Portsmouth, UK, March 29-31, 2015
Social Program

- **Get-together Evening**
  March 29, 2015, from 17.30 to 20.00,
  *The Old Customs House*,
  Address: Vernon Building, Gunwharf Quays, Portsmouth, Hampshire PO1 3TY
  Note: refreshments, snacks and meals available on a pay-yourself basis.

- **Conference dinner**
  March 30, 2015, from 19:00,
  *Strada*
  Address: R2-R3 City Quay, Gunwharf Quays, Portsmouth Harbour, Portsmouth PO1 3TW
  Notes: three courses (starter, main and dessert), drink included;
  fee included in the registration fee.

- **Excursion to Spinnaker Tower and Portsmouth Historic Dockyard**
  March 31, 2015, From 14:00,
  Walking together to the Portsmouth Historic Dockyard and visit both the Spinnaker Tower and a
  ship in the Portsmouth Historic Dockyard
  Note: £18.50/person
Abstracts

1.1 Container Loading Problem: realistic problem instances are needed
Elsa Silva∗, José F. Oliveira∗, António G. Ramos†

∗INESC TEC, Faculty of Engineering, University of Porto, Portugal,
†CIDEM, School of Engineering, Polytechnic of Porto, Portugal

The Container Loading Problem (CLP) is a NP-hard, real-world driven, combinatorial optimization problem, with
a strong economical, safety and environmental impact. Even though the problem has been extensively studied in
the literature, there is still a huge gap between the needs of the transportation industry and what science offers,
as the existing algorithms do not adequately address many real-word needs.
The discrepancies between research and practice are mainly related with the inadequate way practical constraints
have been addressed, sometimes due to over simplified assumptions.
The design of algorithms that simultaneously consider issues relevant to container loading in practice is a pressing
issue. In order to allow the evaluation of the new algorithms, problem generators and/or challenging test problems
for the CLP are also required. This need was already identified in the state-of-the-art-review for constraints on
CLP presented by Bortfeldt and Wäscher (2013), and in fact, there are no problem instances in the literature
considering all the characteristics which are required to test most of the practical-relevant constraints on CLP. In
this work we will try to outline a problem generator which can be able to generate problems instances that fully
characterize realistic constraints. The idea is to extend 2DCPackGen, a problem generator in which the properties
in instances are controlled by a beta probability distribution. The problem generator will include mechanical
properties in the problem instances such as: weight, center of mass, friction coefficient and load bearing strength.

Keywords: 3d rectangular problem generator, container loading, problem generator

This research was partially supported by ERDF through the Programme COMPETE, by the Portuguese Government
through FCT (StableCargo – PTDC/SEN-TRA/121715/2010 and PTDC/EGE-GES/117692/2010) and by the Project
BEST CASE – SAESCTN-PHEC05DT/1/2011 is co-financed by the North Portugal Regional Operational Programme (ON.2
– O Novo Norte), under the National Strategic Reference Framework (NSRF), through the European Regional Development
Fund (ERDF)

1.2 Efficient management of heterogeneous helicopter fleets
Carlos Lamas-Fernandez, Julia A. Bennell, Antonio Martinez-Sykora
University of Southampton, CORMSIS, Southampton, UK

Ranging from military operations to rescuing services, helicopters are versatile aircrafts that can be used in a
large variety of situations. Understanding the ideal size and mix of fleet to meet future operations is an important
strategic decision. Critical to this decision is understanding the number of helicopters needed for the transportation
of different collections of items and passengers and the tradeoff between load and flight range for these scenarios.
In general weight is the critical factor that constrains the loading of the helicopter. Hence, solving the helicopter
loading problem as a one dimensional bin packing problem can support this decision process.
In this work, we consider problems where there is either a single helicopter type or two helicopter types available.
The operations may require the transportation of materials, vehicles, special equipment and passengers, which
must be properly placed into helicopters. The item placement has to meet certain constraints, such as, one
helicopter cannot carry more than a certain weight or a certain number of passengers and some items have
special requirements, for instance, most vehicles must be carried under the helicopter and attached with hooks.
We present an integer programming model and a genetic algorithm to find efficient placements of cargo and
passengers in the helicopter fleet, and aim to minimise the number of helicopters while considering the range
where the fleet can operate.
For a fleet of helicopters of the same type, it is interesting to use as few aircrafts as possible to transport a given
cargo. However, when there is more than one type of helicopter available, it is complex to assess the value of the
resulting fleet. In this case, the total number of helicopters used is not a sufficient objective anymore, as some
types of aircrafts might have advantages against others in some situations, for example, smaller helicopters usually
have higher manoeuvrability. In this context, we present a modification to the ILP and the genetic algorithm
with the aim of finding all the non dominated solutions with a mixed fleet. Once an efficient placement has been
found, we propose a math heuristic algorithm that rearranges the items among the helicopters to maximise the
range where the fleet can operate. The presentation will describe the problem, methodologies and results.

Keywords: 1d multiple bin size bin packing problem, helicopter loading problem, metaheuristic, genetic
algorithm, bin packing, integer linear programming
1.3 GPU sequence based heuristic for the Nesting problem

A. Miguel Gomes, Pedro Rocha, Rui Rodrigues
INESC TEC, Faculty of Engineering, University of Porto, Portugal

The Nesting problem is an hard problem that arises in industries that require the placement of irregular pieces inside a container while minimizing wasted space. This problem is very difficult to address due to its complexity, derived from its geometrical components (dealing with piece geometry and representation, placement, overlap, among others) and combinatorial components (such as the sequence of the pieces and its initial solution). This work focuses on addressing the Nesting problem using a Graphics Processing Unit (GPU) to achieve low computational time, which is significantly large when using traditional approaches based on a CPU. The GPU is optimized to process rasterized geometry, so the geometrical representation used is based on a grid representation with a discrete set of admissible orientations. This rasterized approximation to the pieces shape creates some challenges (considering the accuracy of the representation, and the quality of the final layout) which are addressed though increasing grid quality, and using small gaps between pieces. The construction of the layout is done by an heuristic that generates multiple sequences which is used together with a placement rule (such as Bottom-Left, and Best-Fit) to produce layouts. The main challenge is to analyse the impact of the sequences considering the produces layout quality, in order to provide clues to the identification of rules that enable achieving consistently high quality layouts. Improvements in this area have a significant impact in the industries where this problem arises, mainly considering waste reduction, which translated into lower costs.

Keywords: 2d irregular open dimension problem, Nesting, GPU, heuristics

This research was partially supported by ERDF through the Programme COMPETE, by the Portuguese Government through FCT (StableCargo – PTDC/SEN-TRA/121715/2010 and PTDC/EGE-GES/117692/2010) and by the Project BEST CASE – SAESCTN-PHC6IDT/1/2011 is co-financed by the North Portugal Regional Operational Programme (ON.2 – O Novo Norte), under the National Strategic Reference Framework (NSRF), through the European Regional Development Fund (ERDF)

2.1 A Tabu Search Algorithm for a Two-Objective One-Dimensional Cutting Stock Problem

Antonio Martinez-Sykora*, Chris Potts*, Chris Hantanga*, Robert Donnelly†, Constantine Goulimis†
* University of Southampton, UK, †Greycon Ltd (UK)

We present a tabu search algorithm to solve a one-dimensional cutting stock problem in which, subject to achieving the minimum waste (trim loss), the number of different cutting patterns is to be minimized. This problem has been proposed by Greycon Ltd and is motivated by a real application.

In the problem considered, there is a supply of stock rolls all having the same width. A roll can be cut into smaller rolls of different widths, and there is a demand for each width that corresponds to a customer order. The objective is to find the solution with the smallest number of patterns among those solutions with minimum waste. In the literature, there are well-known column generation algorithms capable of solving large instances of the trim loss minimization problem to optimality using a few seconds of computation time. The master problem of the column generation approach is to be used as the core of the proposed tabu search algorithm. A tabu list containing some of the patterns is required in order to avoid repetitions and to diversify the search of the solution space.

Computational tests are performed on a set of 34 instances that have been supplied by Greycon. The optimal solution for each instance is given in terms of the minimum waste (trim loss). Computational results obtained by applying the proposed tabu search algorithm show that, relative to the solutions supplied by Greycon, a reduction of the number of cutting patterns is observed in more than half of the instances. Moreover, the number of patterns is reduced up to 25% in some instances. We present some lower bounds and greedy algorithms based on local search movements in order to assess the effectiveness of the proposed tabu search algorithm.

Keywords: 1d single stock size cutting stock problem, 1d-bin packing problems, pattern reduction, column generation, tabu search

2.2 A biased random-key genetic algorithm for the unconstrained unequal area facility layout problem

José Fernando Gonçalves
LIAAD, INESC TEC, Faculdade de Economia do Porto, Universidade do Porto, Portugal
This paper presents a biased random key genetic algorithm (BRKGA) for the unconstrained unequal area facility layout problem (UUA-FLP) where a set of rectangular facilities with given area requirements has to be placed, without overlapping, on a rectangular floor space. The objective is to find the location and the dimensions of the facilities such that the sum of the weighted distances between the centroids of the facilities is minimized. A hybrid approach combining a BRKGA, to determine the order of placement and the dimensions of each facility, a novel placement strategy to position each facility. The proposed approach is tested on 100 random datasets and benchmark datasets taken from the literature and compared against other benchmark approaches. The quality of the approach was validated by the improvement of the best known solutions for several extensively studied benchmark datasets.

**Keywords:** 2d rectangular open dimension problem, facilities planning and design, facility layout, biased random-key genetic algorithms, random-keys

This work has been supported by project PTDC/EGE-GES/117692/2010, under the National Strategic Reference Framework (NSRF), through the European Regional Development Fund (ERDF) and the Programme COMPETE, and by national funds, through the Portuguese funding agency, Fundação para a Ciência e a Tecnologia (FCT).

### 2.3 A Join & Cut Problem

Constantine Goulimis, Denis Jaubert

*Greycor, UK*

We describe here a problem occurring in the paper industry, which is an extension to the traditional 1D cutting stock problem (CSP). Here, the input reels (characterised by width and length) can be joined (spliced) together to form staircase-shaped strips of material from which the required customer reels can be slit. The objective function minimises the wasted area, analogously to 2D problems. We believe that this is the first time this particular problem has been described and solved. We present a heuristic algorithm and discuss the solutions.

**Keywords:** 2d rectangular multiple stock size cutting stock problem, cutting stock problem, splicing, paper industry

### 2.4 Bin Packing with Due Dates

Claudio Arbib*, Fabrizio Marinelli†

*Università degli Studi dell’Aquila, Dipartimento di Ingegneria/Scienze dell’Informazione e Matematica, Italy, †Università Politecnica delle Marche, Dipartimento di Ingegneria dell’Informazione, Italy

In the Bin Packing problem (BP), items of different sizes must be assigned to a minimum number of bins. In the k-dimensional problem (kBP), items and bins are closed k-intervals. Regarding each item as a job that requires unit time and some resource amount, and each bin as the total (discrete) resource available per time unit, the kBP objective is the minimization of the makespan.

We generalize the kBP problem to Bin Packing and Scheduling (kBPS) by changing the objective to any (even non-regular) function of the completion time of the jobs. Interesting applications are those in which each part (= job) is to be produced within a specific due date. Typical examples of regular functions are maximum lateness, weighted sum of jobs tardiness, etc. In practice, a convex combination of such functions is often considered.

When the scheduling term in the objective function is the weighted sum of jobs tardiness or of tardy jobs, one can specialize an exact formulation for the Cutting Stock Problem with Due Dates (Arbib and Marinelli, 2014). An alternative, more general and perhaps more effective approach is to use an ad-hoc time-indexed formulation. This approach, which can encompass Dantzig-Wolfe decomposition and, consequently, column generation, is close to that described by van den Akker et al. (2005) for general time-indexed formulations applied to parallel scheduling. When column generation is used, the difficulty of k-dimensional packing is relegated to the pricing problem. To find a lower bound for the 2BPS one can then solve a relaxed 2-dimensional pricing problem by the arc-flow formulation (Macedo, Alves and V. de Carvalho, 2010). In alternative, one can implement conservative scales (Belov et al., 2013) via a time-indexed formulation for 1BPS. In this talk we just discuss a preliminary computational experience carried out for 1BPS with Lmax as scheduling term of the objective function.

**Keywords:** Kd rectangular bin packing problem, bin packing, scheduling, integer programming, due dates
3.1
Upper Bounds for Heuristic Approaches to the three-dimensional Strip Packing Problem
Torsten Buchwald, Guntram Scheithauer
Dresden University of Technology, Institute of Numerical Mathematics, Germany

We consider the COMB-3D heuristic for the three-dimensional Strip Packing Problem. This heuristic combines an implementation of a First-Fit Decreasing-Height, called FFDH-3D heuristic, and the algorithm of Steinberg. Furthermore, it is known that the absolute worst-case performance ratio of this heuristic is at most 5.

In this presentation, we show an example which proves that this absolute worst-case performance bound is tight. It reveals that this absolute worst-case performance bound can only be reached by instances which fulfill a certain property. Using induction, we succeeded to prove an improved absolute worst-case performance bound for the case that this property is violated. Again we construct examples to show that this absolute worst-case performance bound is tight and is at least 4.5. Furthermore, we show that the absolute worst-case performance of the COMB-3D heuristic is at most 4.25 if the length of each item is not smaller than its width and the lengths of the container is not greater than its width. This conditions can be fulfilled for the z-oriented three-dimensional Strip Packing problem, where length and width of items can be interchanged but the height of the items is fixed. We also proved that this absolute worst-case performance bound improves to 4, if the container has a squared base area. This theorem is proved by a comprehensive case-by-case analysis and a special kind of induction, where the induction index i increases from $i - 1$ to $i$ or $i + 1$.

Furthermore, we show that if all items and the container have squared base area, the absolute worst-case performance ratio of the COMB-3D heuristic is at most 3.25. For proving this theorem we had to consider an unsolved problem for the two-dimensional Bin Packing Problem:

Can a set of items of length and width at most $\frac{1}{2}$ and total area at most $\frac{5}{9}$ be packed into a bin of length and width 1?

By a comprehensive case-by-case analysis we proved that such a set of items can be packed into the bin if all items are squares. This result solves the problem for a special case and is also tight, which means that $\frac{5}{9}$ is the maximum total area bound.

Keywords: 3d rectangular open dimension problem, cutting and packing, bin packing problem, strip packing problem, heuristics, performance bounds

3.2
Extended formulations for an exact 4-stage restricted guillotine bin packing problem with rotation
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We consider and solve exactly an exact 4-stage restricted guillotine bin packing problem with rotation. This problem is NP-hard and combinatorial methods or compact MIP models are known to be weak. Nevertheless so-called extended formulations (pseudo-polynomial, Dantzig-Wolfe decomposition, ...) provide good results on similar problems. We propose such formulations for our problem and compare them experimentally.

The first one is based on a Dantzig-Wolfe decomposition. The subproblem is an exact bounded 4-stage restricted guillotine knapsack problem with rotation. We first design a dynamic program to solve this subproblem in an unbounded version. Then we note that such dynamic program is equivalent to seek a flow of value one in a hypergraph. Therefore the subproblem can be written as a hyperflow MIP model of a pseudo-polynomial size. Finally we add knapsack constraints to this model to ensure that the demand of each item is respected. We also describe some rules to reduce the size of hypergraph and therefore the size of the MIP model. They use information from the problem instance and the hypergraph structure.

The same hyperflow MIP formulation can be used to model the whole problem. The only difference is that instead of searching for a maximum cost hyperflow of value one, we minimize the size of the hyperflow which covers all demands.

Keywords: 2d rectangular bin packing problem, bin packing, extended formulation, hypergraph, flow model

3.3
A Scalable Approach for Large-Scale Instances of the K-Staged Two-Dimensional Cutting Stock Problem with Variable Sheet Size
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This work focuses on the two-dimensional cutting stock problem with variable sheet size (2CSV) in which we are given a set of rectangular element types $E$ with corresponding demands and a set of stock sheet types $T$ of certain quantities. Both elements and sheets can be rotated by 90°. The objective is to find a set of cutting patterns $P = P_1, ..., P_n$, i.e. an arrangement of the elements specified by $E$ on the stock sheets specified by $T$ without overlap and using only up to a given number $K$ of stages of guillotine cuts, s.t. the number of used sheets is minimal. In particular, we are dealing with large-scale instances from industry in which the number of different element and sheet types is moderate but the demands for the element types are rather high. In this context, a crucial aspect besides solution quality is also the design of efficient algorithms and data structures to avoid excessive runtimes.

To address this issue we employ a cutting tree data structure that stores multiple congruent sheets and subpatterns by referencing at each node only one respective child node and storing an additional quantity. Using this data structure we can efficiently exploit symmetries already during solution construction. To this end we propose a congruency-aware construction heuristic that is able to insert multiple instances of a given element type efficiently at once by simultaneously altering multiple congruent subpatterns. This heuristic is embedded in a framework sequentially generating the solution sheet by sheet, allowing us to address the problem of selecting the sheet type to be used whenever a new sheet needs to be started. A local lookahead in the fashion of the Pilot method is performed in order to choose the sheet of the type that is most promising in terms of quality.

Preliminary experiments on large-scale instances from the cutting industry show that the approach yields solutions of reasonable quality in short time and demonstrate its scalability. The proposed approach constitutes a solid basis for the subsequent application of advanced metaheuristics, such as very large neighborhood search or variable neighborhood search, in order to further improve the results at the cost of higher computing times.

**Keywords:** 3d rectangular multiple stock size cutting stock problem, two-dimensional cutting stock, insertion heuristic, scalability

### 3.4 New inequalities for 1D relaxations of the 2D rectangular strip packing problem

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We investigate a heuristic for the two-dimensional rectangular strip packing problem without rotation that constructs a feasible packing by placing one-dimensional cutting patterns obtained by solving the horizontal bar relaxation, the LP relaxation of the one-dimensional cutting stock problem. To represent a solution of the strip packing problem, a solution of the horizontal bar relaxation has to satisfy, among others, the vertical contiguous condition. That means there must exist such an ordering of the cutting patterns that all items representing one rectangle are located in consecutive patterns. We assume that the strip is filled from bottom to top. If a cutting pattern is placed at the bottom of the strip the $y$-coordinates of the corresponding rectangles in a two-dimensional packing are zero. A cutting pattern that contains all items of the first pattern except the items with minimal related rectangle height would continue the first pattern in vertical direction. Furthermore, we know that the $y$-coordinates of the rectangles corresponding to the items that are in the second cutting pattern but not in the first pattern are equal to the minimal height occurring in the first pattern. To strengthen the horizontal bar relaxation with respect to that vertical contiguity we define bottom patterns and formulate inequalities that are based on the knowledge of $y$-coordinates. The new inequalities ensure that if a one-dimensional cutting pattern is used in the solution of the relaxation there exists at least one cutting pattern with usage greater than zero that continues that pattern and thus we obtain a solution matrix with a sub matrix that has the consecutive ones property.

Additional to the vertical contiguous condition a solution of the horizontal bar relaxation must ensure that all items representing one rectangle have the same $x$-position in each pattern. The considered one-dimensional cutting patterns do not provide any information about the order of the contained items. Because of that the following two strategies are integrated in the process of column generation: identify and forbid $x$-position infeasible cutting patterns and prevent the generation of $x$-position infeasible cutting patterns. We tested, among others, the waste-free classes of Hopper with known optimal strip height. All obtained results improve that of our heuristic without considering vertical contiguity and for most of the instances with a number of rectangles up to 29 an optimal solution was found.

**Keywords:** 2d rectangular open dimension problem, 2d strip packing, heuristics, 1D cutting pattern, contiguity property
4.1 A Heuristic Algorithm for the Container Loading Problem of Challenge Renault/ESICUP

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For the problem of the challenge Renault/ESICUP, we are given a set of cuboid items, where each item has a deterministic shape and size, a weight, and is related to a single product. Some of the items may be rotated only in one dimension. We are also given a set of bins, where each bin has a deterministic shape and size and also an upper limit on the total weight of items it can contain. The objective is to pack all the items into bins so as to minimize the total volume used. Each bin contains stacks packed on the two-dimensional floor. Each stack contains layers that are packed one above the others. Each layer contains a set of rows, where each row is composed of items packed on the floor of layer.

We propose a heuristic algorithm to solve this problem. The basic idea is a two-phase greedy strategy: the first phase creates high-quality stacks, and the second phase packs the generated stacks into bins based on the fact that once the stacks are generated, the problem reduces to the two-dimensional rectangle bin packing problem. We use the (one-dimensional) knapsack problem to generate high-quality stacks until all the items are combined into stacks. After generating stacks with all of the items, we utilize a well-known heuristic algorithm for the rectangle packing problem, the best-fit algorithm, to create high-quality bins. We call the best-fit algorithm repeatedly, and in each iteration, to choose a packing layout of stacks in a bin to be used in the final solution, we call it twice, once in the widthwise direction and another in the lengthwise direction, until for each of the two calls, all the stacks are packed into bins. Then, in this iteration, the packing layout of stacks in the bin with the greatest occupation ratio is selected for the final solution. We repeat such packing and selection operations to create packing layouts of stacks in bins until all the stacks are packed into bins.

We are selected for the final phase of the challenge Renault/ESICUP and will present our final computational results on the datasets provided by the organiser.

Keywords: 3d rectangular MBSBPP, ESICUP - Renault Container Loading Challenge (2015), container loading, bin packing, greedy strategy, knapsack problem

4.2 A randomized multi-start algorithm for the Container Loading Problem of Renault

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Renault is a major vehicle manufacturer, with factories in many different countries. As vehicle parts are moved between factories, the company has to solve large truck/container loading problems on a daily basis. In each problem, there is a large quantity of small items that have to be packed into bins (trucks, containers) of different sizes and the main objective is to minimize the total volume of the bins used, as well as some secondary objectives. Three-dimensional bins contain stacks packed on the floor. Each stack is composed of layers that are placed one above the other. A layer contains a set of rows, which are composed of items. Besides the usual geometric constraints preventing overlapping and forcing the items to be completely inside the bin, there are many constraints on the way in which pieces can be put together to form rows, rows to form layers and layer to form stacks. There are also constraints for the total weight of the pieces in each bin, the weight the pieces in the base of the stack can bear and on the orientation of the pieces. Since items are sent almost every day, some of them can be left out of the packing, packed in bin 0, and sent another day, within some limits for each type of item.

We have developed a randomized multi-start algorithm for building feasible solutions within the time limits set by the company. The algorithm fills bins one at a time until all the pieces are packed. As there are several bin types, each time a new bin has to be created, we fill a tentative bin of each different type and choose the bin with the best ratio of volume used. The process of filling a bin follows these steps:

1. Select a free location on the floor of the bin.
2. Select an item to be the base of a new stack at the selected location.
3. Construct compatible layers for the new stack, satisfying the constraints for rows and layers.

Once a location has been selected, we use a list of unpacked items ordered by a given criterion. We use several criteria, involving the width, the area, and the urgency of the items, defined as the number of pieces that can be left unpacked. We select the first item in the list that fits into the location and does not violate any other constraint. When selecting an item for the base, we consider its possible orientations and choose the one that better fills the selected space.
4. Construct a compatible top layer when a new regular layer cannot be generated.

The top layer of each stack does not have to follow the rules used for building the other layers. Therefore, a special procedure is used to fill this top layer. This can be done every time a stack is built or when all the stacks filling a bin have been built. We have also studied the possibility of merging several stacks with the same dimensions so as to have a larger area on which to build the top layer.

5. Check if the solution is feasible.

The number of items of each type in the bin 0 is limited, so this condition has to be checked and, if necessary, some pieces are exchanged between this and the other bins.

In the constructive process described above we randomize the selection of the base of the stack and the order of the items that compose the layers above it. From the set of all possible bases, a restricted candidate list (RCL) is built and the base is selected randomly from this list. We have studied two alternative methods for building the RCL: RCL value-based, in which the candidates are selected according to their quality, and Sampled plus construction (SPC), in which only a random sample of possible bases is built and considered. The items to compose the layers above the base are selected at random from the set of compatible layers.

Instead of filling only one tentative bin of each type, we fill several tentative bins using different orderings and repeating the process several times. We choose the best tentative bin according to the percentage of volume occupied, but if all the items fit into one bin, this bin is selected.

The algorithm runs until it reaches a maximum number of iterations without improving the best solution obtained or the time limit is reached. We use the OpenMP library in order to parallelize the process. The algorithm is run over each instance in parallel, using as many threads as there are cores in the processor. We have solved the sets of instances A and B provided by the company and we have improved on the best results reported so far.

Keywords: 3d rectangular multi bin size bin packing problem, ESICUP-Renault Container Loading Challenge (2015), container loading, metaheuristics, multi-start

4.3 A heuristic decomposition approach to the ESICUP 2015 Challenge

Container Loading Problem

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The Container Loading Problem is an important problem in the field of logistics and transportation. It appears that real world problems cannot always be solved easily, due to the large number of complex constraints. This work addresses the problem introduced by Renault on the occasion of the ongoing ESICUP 2015 challenge.

The problem presented for ESICUP challenge is different from most container loading problems described in literature. In brief, the problem considers putting items in stacks and packing these stacks in containers. Stacks are composed of layers, which in their turn contain rows of similar-size items. One container is left behind for the next shipment, and a set of available container types is defined for each problem.

Besides the usual constraints for container loading, related to the size and weight of the items, a number of specific constraints have to be taken into account. The first constraints determine how items should be packed into stacks. These include, among others, weight bearing constraints. Other constraints define how the materials can be put together in a stack. The most specific constraints relate to the container that is left behind. Shipment can only be postponed for a small percentage of the items of each product type, and the container left behind must be the one holding the smallest volume.

We produced a decomposition procedure based on heuristic strategies. The procedure contains three components, each solving one of the interconnected subproblems: (i) bin builder, (ii) stack builder and (iii) layer builder algorithms. These components are combined in an algorithm inspired by the Greedy Randomized Adaptive Search Procedure (GRASP).

The general algorithm can be divided in two phases: construction and refinement. The constructive part iteratively packs items in containers with the bin builder procedure, which solves a 2D bin packing problem with weight constraints. The stacks to be packed are dynamically generated by both the stack and layer builder procedures. In each iteration of the constructive algorithm, the container type is chosen in a greedy-randomized way, considering the highest usage rate.

After a feasible solution is obtained, different intensification strategies are applied in parallel. These strategies include a ruin-and-recreate method for rebuilding parts of the solution and a local search procedure. The local search includes standard insert and rearrange moves, an ejection chain neighborhood and an order-based shaking method.

Seventeen teams of researchers registered for the international challenge. Based on the results obtained during the qualification phase, eight out of the twelve teams were selected for the final phase. The approach presented in this abstract was rated first in the qualification phase, as it produced the best results for both the short runtime (1 hour) and the long runtime (6 hour) categories.
**Keywords:** 3d rectangular multi bin size bin packing problem, ESICUP-Renault Container Loading Challenge (2015), container loading problem, best fit, decomposition strategies

### 4.4 Genetic approach to ESICUP Renault Container Loading Challenge 2015

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This research was inspired by ESICUP Challenge 2015 which was sponsored by the automotive maker RENAULT with the cooperation of the Operations Research team of the Bordeaux University. The problem is related to a container loading for the logistics platforms. The full problem statement is available at [http://challenge-esicup-2015.org/](http://challenge-esicup-2015.org/). Briefly there is a number of items and there are several bin types. The aim is to pack all the items into bins using a set of bins of minimum possible total volume. During packing items are grouped in rows, rows are grouped in layers, layers are grouped in stacks and stacks are put into bins. Also there is a number of practical constraints described in the statement.

Our approach is based on narrowing the class of feasible solutions. Afterwards we use different heuristic and genetic methods. We note that initial data usually contains groups of essentially the same objects, and therefore work with groups of items instead of single items. Next, the approach allows only layers with the same type of items. These observations and simplifications automatically satisfy a big number of practical constraints and give significant computational speedup. The heuristics are based either on genetic selection or greedy selection according to some metric. The process of packing is split into the following stages: preprocessing (when the groups are created and sorted with different comparators), processing (when some set of answers is formed) and postprocessing (when some local optimizations are applied to the answers). In the processing we vary metrics, bin types, genetic approaches, two-dimensional fillers, that put stacks, and layer creation strategies. A baseline uses greedy approach and is used as one of the benchmarks.

There is a number of two-dimensional fillers used: known heuristics for orthogonal two-dimensional bin-packing, including shelf and guillotine approaches along with some other algorithms. Main metrics are: density of volume/weight/area usage in the last bin (in online greedy approach with last bin closing), and current used bins total volume increased by a lower bound for not yet packed items. Some trivial lower bounds are used as benchmarks for evaluation.

**Keywords:** 3d rectangular MBSBPP, ESICUP - Renault Container Loading Challenge (2015), genetic algorithms

### 5.1 A hole filling heuristic for the Nesting problem with continuous rotations

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Nesting problems commonly arise in industries where there is a need to efficiently place irregular shaped pieces inside a container while minimizing waste. This problem is very complex and difficult to tackle, mainly due to the challenges derived from its geometrical and combinatorial component. The geometrical component requires an efficient method to deal with the accurate representation and positioning of the pieces, considering overlaps and possible orientations. The geometrical representation imposes limitations which prevent certain approaches to be used to address this problem, such as the ones regarding admissible orientations. The combinatorial component deals with the sequencing of pieces (in the initial solution), which enables determining the initial relative positions between pieces. In this work we address a strip packing problem with continuous rotations where irregular pieces are represented by sets of circles. The placement positions and orientations are computed using a Non-Linear Programming (NLP) model and solver, which converge an initial solution to a local minima.

This work focuses on the approach to place pieces inside the holes of a layout (Hole Filling heuristic) which is used in a Two-Phase approach, to check the piece-to-hole compatibilities, their placement positions and orientations inside the holes. Finding the compatibility between a piece and a hole (determining if the piece fits inside the hole, and the best position and orientation to place it) is a very difficult problem to solve.

The Hole Filling heuristic allows the use of an approach based on two distinct phases. In the first phase, the pieces are divided into two different groups (separated by piece size), and selecting the set of the largest pieces, they are compacted to form an initial layout. In the second phase, the remaining smaller pieces (from the second set) are selected and positioned inside the holes and empty space between the pieces compacted in the first stage, using the Hole Filling heuristic. All pieces are then compacted.

**Keywords:** 2d irregular open dimension problem, nesting, continuous rotations, non-linear programming, circle covering

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5.2 An investigation of constructive heuristics in 2D-irregular shaped strip packing problems with free rotation

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Cutting and packing problems with two-dimensional irregular shaped pieces is an established area of research, where many different local search methodologies have been applied along with a variety of problem specific design decisions. In this study we focus on analysing the effectiveness of different design decision, and their combinations, to develop efficient and fast constructive heuristics for packing problems with two-dimensional irregular pieces.

A key variable the study considers is allowing the rotation of pieces. While many applications may dictate the freedom of rotation, it is interesting to evaluate the relative benefit and computational cost of different strategies.

We investigate three rotation options; 1) zero angle rotation, 2) finite angle rotation and 3) free angle rotation.

A second variable we consider is the use of hole-filling verses no hole-filling with respect to using the inner spaces generated by the already placed pieces. Finally, two placement policies are evaluated: classical bottom left and a minimum length strategy. The constructive heuristic operates as a single-pass construction method which generates the packing layout piece by piece. The most promising variants of the constructive heuristic are embedded into a Jostling approach that iteratively applies the constructive heuristic in order to change the sequence of insertion of pieces at each iteration.

Performance of each procedure is evaluated using two parameters; algorithm execution time and area utilization. Computational results for irregular shaped heterogeneous polygons are generated using benchmark data sets found on the European working group on cutting and packing (ESICUP) website. Findings of the study into the constructive procedure demonstrate that, irrespective of the use of hole-filling, the utilization of area improves when the degree of rotation is improved. Moreover, comparing variants with and without hole-filling, there is no significant difference in area utilization when free rotation is permitted. Comprehensive results are presented for the constructive procedure Jostling.

Keywords: 2d irregular open dimension problem, free rotation of pieces, hole-filling, constructive packing heuristics, irregular shaped packing

5.3 A robust model for the irregular strip packing problem

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Irregular cutting stock problems have been extensively studied in literature on the last decades. A common variant of this problems is the irregular strip packing problem. The problem aims to place concave and convex pieces in a board with fixed height and infinite length. All the pieces must be contained in the board and the pieces must not overlap. The objective is minimize the used board length.

Despite the number of solution approaches used to solve this problem, there are only few exact methods to solve it. All the exact approaches proposed in the literature use the nofit polygon to avoid overlaps between the pieces. The nofit polygon needs to be computed a priori and a simple modification, for example a rotation, invokes the update of several nofit polygons.

In this work, we propose a mathematical model to solve the irregular strip packing problem that uses only the board and the pieces geometry information. Direct trigonometry is used to avoid overlaps between the pieces. The model is robust in the sense that the standard formulation can solve problems with pieces of any polygonal shape.

In the model, the constraints which ensure that the pieces are entirely inside the board are built based on the geometric information of the pieces and of the board, defining where the reference point of each piece can be placed. To explain the no overlap constraints, consider first two convex pieces A and B with the sequence of vertices defined in a clockwise orientation. Then, piece A does not overlap piece B if all the vertices of piece A (or B) are over or at right side of exactly one line defined by an edge of piece B (or A). Considering all the constraints that must be created to analyse the position of pieces A and B, only one must be satisfied.
Non convex pieces are divided in the minimum number of convex polygons. The same idea used to avoid overlaps of convex polygons can be applied over each pair of polygons of different pieces. The proposed method was applied to the instances from the literature. Comparing the solutions with the best model from the literature our approach is competitive and the amount of information used to solve the problem is substantially smaller. With the proposed model, solving an irregular strip packing problem does not depend on advanced geometric structures. Changes on the piece shapes, such as rotations or scaling can be made directly on the instance and no additional computation is necessary. Moreover, as the pieces are divided in convex polygons, all the pieces are treated in the same manner by the model. The model can be considered robust in the sense that it does not need special constraints to pack pieces special characteristics, such as holes and concavities. **Keywords:** 2d irregular open dimension problem, irregular strip packing, direct trigonometry, mathematical model

### 5.4 A Residual-Space-Maximized Algorithm for Nesting Problems

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Two dimensional irregular cutting and packing (C&P) problems, known as nesting problems, arise across a board spectrum of industries. This paper focuses on 2D nesting problems, encompassing bin packing and strip packing. The proposed algorithm is based on a policy that the residual space at each step of packing, i.e. the unused region, should be maximized. This enables subsequent items to be packed into the residual space with maximum likelihood.

Input items are sorted in an area-descending sequence. Large items are packed before small ones. When packing each item, the minimum bounding box of the item is first calculated; several angular positions with respect to the minimum bounding box are tested for packing. At each angular position, the smallest residual space that can accommodate the item is used for packing. In that space, all feasible packing positions are tested and a performance value is calculated based on an evaluation metric. The position that produces the best performance value is selected as the packing position of the item.

The algorithm is implemented by based on a line segment data structure. Geometric data of an item, i.e. coordinates of vertices, are rasterized to a regular 2D grid. Line segments along one direction of the grid are constructed to represent the item. Operations such as placement of an item and updating a residual space can be efficiently implemented based on the data structure.

Instances from openly available datasets and self-generated problems are used to test the validity and efficiency of the algorithm. Experimental results show that with less computational overhead, the proposed algorithm is able to reach comparable solutions to those of existing algorithms. **Keywords:** 2d irregular open dimension problem, nesting problem, residual-space-maximized packing, irregular item packing

### 6.1 Several constructive heuristics for the three dimensional Multiple Bin Size Bin Packing Problem with air transportation constraints

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The problem tackled here is the selection of containers in order to pack a set of cuboid boxes. The aim is to minimize the unused space inside the selected containers. The set of boxes is highly heterogeneous while there are few types of containers to select. This is a three dimensional Multiple Bin Size Bin Packing Problem (MBSBPP) in which, in addition to the geometry constraints, some additional constraints encountered in practical packing situations are considered: the container weight limit, the orientation constraints, the load stability, the load-bearing strength or fragility of the boxes and the weight distribution within a container. Moreover, as the original problem is an air cargo application, we extend the definition of the MBSBPP to include situations in which the large objects may be truncated parallelepipeds. Indeed, in this context, containers are called Unit Load Devices (ULD) and may have specific shapes to fit inside aircraft.

The first approach was to develop a mixed integer programming formulation for this optimization problem and to solve it with branch-and-bound algorithm. This model has been implemented in Java, using CPLEX library, and tested on small instances. As expected, the computational times were rather important. Therefore, the aim of the current research is to develop set of constructive matheuristics based on that formulation.
Our first try is to adapt the Relax-and-Fix (R&F) heuristic which is an iterative procedure which decomposes a large-scale MIP problem into several easier subproblems in order to get an initial feasible solution for the original problem. The integrality restriction of some variables is relaxed in subproblems, reducing the computational times. Two other MIP-based constructive heuristics, inspired from the R&F heuristic, have also been developed adapted to our context. The Insert-and-Fix (I&F) heuristic relies on the idea to insert boxes step by step inside containers. In addition to this heuristic, the Fractional Relax-and-Fix (FRF) heuristic is based on the merge between the two previous methods: at each iteration of this algorithm, a set of boxes is inserted (as in the I&F) while a subset of their variables has the integrality restriction relaxed (as in the R&F). These three MIP-based constructive heuristics are compared to a greedy best-fit decreasing algorithm designed especially for this purpose.

Keywords: 3d rectangular multiple bin size bin packing problem, bin packing, air transport, matheuristics

6.2 Routing problems with 3D loading constraints and reloading effort
Andreas Borlfieldt, Dirk Männel
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The talk deals with reloading effort that can occur in routing problems with 3D loading constraints (3L-VRP). It is assumed that vehicles are loaded and unloaded from the rear side. We speak about reloading effort if goods must be moved within the loading space of a vehicle after loading and before unloading. For example, if the well-known Last-in-first-out (LIFO) condition is ignored goods have to be (temporarily) reloaded to allow for unloading other goods that have reached their destination.

Since reloading of goods is often undesirable or even impossible (because of the absence of working power or equipment at customer sites), we then investigate by which means reloading effort can be avoided. Three types of means are available: (1) packing constraints like LIFO, (2) routing patterns and (3) the separation of the loading space. It is shown that these means together will suffice for the whole spectrum of basic routing problems although different routing problems require a different “policy” to avoid any reloading effort. For example, in the vehicle routing problem with backhauls where every customer is associated with a linehaul as well as a backhaul quantity, reloading effort can only be avoided if the loading space is separated in a linehaul part and a backhaul part while the separation of the loading space is not necessary for other basic types of vehicle routing.

The total travel distance is the primary optimization criterion for 3L-VRP. It turns out that the avoidance of reloading effort always results in greater total travel distance. Inversely, by tolerating reloading effort one can save travel distance. Thus, 3L-VRP should be considered multi-objective optimization problems (at least if practical circumstances allow to cope with a certain amount of reloading effort) and this is done in the following part of the talk.

Finally, some preliminary results are presented that were obtained for several 3L-VRP by algorithms by the authors that follow different approaches to take reloading effort into account.

Keywords: 3d rectangular placement problem, packing, routing, routing problems with 3D loading constraints, reloading effort

6.3 A decomposition-based approach to the safe vehicle routing problem with sequential loading
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Road freight transport aims to deliver cargo over public roads, at the lowest possible cost and without causing damage to the vehicle, to other road users or to the load itself. In order to ensure cargo safety, load units should be prevented from causing high impact forces on other structures in their proximity. Therefore, shifting or tilting load units during sudden manoeuvres of the vehicle should be avoided. Additional restraining methods are often costly and time consuming. Cargo safety is preferentially inherent to the loading scheme. By eliminating empty space inside the vehicle, undesirable load movements can be avoided.

Sequential loading constraints substantially confine the possibilities for optimizing the loading scheme. The unloading sequence, and therefore also the vehicle’s route, is considered part of the optimization problem. The objective is to minimize the total cost, which is determined as the sum of the route cost and the cost of additional securing methods.

This “safe vehicle routing problem”, or SVRP, can be modeled as a decomposition of two subproblems: 1) the vehicle routing problem and 2) the container loading problem with sequential loading and safe packing constraints.

The approach presented in this talk consists of a simulated annealing procedure for the vehicle routing problem and a GRASP-based heuristic for the container loading problem. The simulated annealing procedure applies a
few basic heuristics for updating routes. The packing costs corresponding to the routes thus obtained, depend on
the container loading subproblem’s solution quality. New packing schemes for a given route are constructed in a
greedy randomized way. These subproblem solutions are afterwards locally improved by simple heuristics. The
cost of the best packing scheme is returned to the simulated annealing procedure in an iterative way. Experiments
on real data reveal potential safety increase of freight transport, without significantly increasing costs.

**Keywords:** 3d rectangular placement problem, safe vehicle routing, container loading

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### 6.4 Dynamic stability metrics for the Container Loading Problem

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The Container Loading Problem is a real-world driven combinatorial optimization problem that addresses the
spatial arrangement of cargo inside containers so that the use of the containers’ space is maximized. As an
assignment problem it can have two basic objectives, the maximization of the value of the cargo loaded, when the
number of containers is not sufficient to accommodate all the cargo, or the minimization of the cost of containers
when there are sufficient containers to accommodate all cargo.

Even though the problem has been extensively studied in the literature, there is still a huge gap between the
needs of the transportation industry and what science offers, as the existing algorithms do not address adequately
many real-word needs, namely related to cargo stability.

In the literature, cargo stability is considered as one of the most important practical-relevant constraints of the
Container Loading Problem. Two type of approaches can be found; one that only addresses static stability and
another that makes a distinction between static and dynamic stability. Static stability concerns the stability of
the cargo during the loading process into the container and dynamic stability refers to the stability of cargo during
transportation.

The majority of the authors only focus on static stability and only a handful address both static and dynamic
stability. The dynamic stability constraint has been evaluated mainly by two metrics: the average number of
support boxes per box, and the percentage of boxes with insufficient lateral support. These metric have been
used as a proxy for the real-world dynamic stability constraint and have conditioned the algorithms developed for
this problem. They have the advantage of not being expensive from a computation perspective. However, they
do not necessarily ensure a realistic measure of dynamic stability.

The aim of this work is to present a new set of metrics to evaluate the dynamic stability in the Container Loading
Problem under a realistic framework. A physics simulation tool based on a physics engine simulates the dynamic
behavior of cargo arrangements and measures dynamic stability based on the geometric displacement of boxes
inside the container and the Damage Boundary Curve fragility test method. A set of new geometric dynamic sta-
bility metrics based on the allowable motion of a box inside the container is proposed and evaluated by measuring
the correlation between them and the physics dynamic simulation results.

**Keywords:** 3d rectangular placement problem, dynamic stability, physics engine, container loading problem

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Notes
Maps
Richmond Building – Ground floor

- LT2 (RB0.12) – Open/Closing Session and Presentation Sessions
- LT3 (RB0.09) – Presentation Sessions
- Atrium – Registration, Refreshment, Coffee breaks
The 12th ESICUP Meeting will be held at Richmond Building in the University of Portsmouth. The institute is located close to the city centre and two main train stations in Portsmouth - 'Portsmouth & Southsea' and 'Portsmouth Harbour' (5 minutes by walk from the train station).

Map of Portsmouth

- pin – Richmond building in the University of Portsmouth
- circle – Old Customs House, Get-together venue
- triangle – Strada, Conference dinner venue
- star – Spinnaker Tower, Trip to Portsmouth Historic Dockyard