# 14th ESICUP Meeting

**Liège, Belgium, May 3-5, 2017**

**Organization**

THE ASSOCIATION OF EUROPEAN OPERATIONAL RESEARCH SOCIETIES

ESICUP CUTTING AND PACKING

Management School - University of Liège

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**Organised by**:

ESICUP – EURO Special Interest Group on Cutting and Packing

HEC Liège, Management School – University of Liège

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# Welcome

Dear Friends,

Welcome to the 14th 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), Ibiza (Spain), and this 14th meeting is now held in Liège (Belgium).

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

Liège, is located along the Meuse River in Belgium's French-speaking Walloon region. For a long time an important commercial and cultural hub, its old town has plenty landmarks dating to the medieval era, including the Romanesque Collegiate Church of St. Bartholomew. The Grand Curtius Museum, located in a 17th-century mansion, exhibits archaeological treasures and art. The Opera Royal de Wallonie has staged operas since 1820. The top things to do in Liège include visits to la Montagne de Bueren (with its 400 steps) and walk to the Coteaux de la Citadelle (remnants of the Liège fortification that formed the origins of the city), the Liège-Guillemins railway station, the Parc de la Boverie and its new footbridge, the Grand Curtius Museum, the Archeoforum (tour through 9000 years of history) and Liège Cathedral.

HEC Liège, which is hosting this meeting, is the Management School of the University of Liège and offers programs in the fields of economics, finance, business administration, entrepreneurship and engineering management. It was created in 2005 by the merger of Hautes Etudes Commerciales de Liège (HEC-Liège), a private institute, created in 1898 and the Economics and Business Administration Department (le Département d'économie et l'Ecole d'Administration des Affaires) of the University of Liège. The School is internationally recognized for the excellence of its research and its wide-ranging educational portfolio in the fields of management and economics (EQUIS award delivered in 2016 by the International accreditation organism EFMD). At the regional level, HEC Liège is a significant contributor to the successful development of its region.

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

José Fernando Oliveira
University of Porto
Program Chair

Célia Paquay
University of Liège
Local Organizer Chair

# Information for Conference Participants

### MEETING VENUE

The 14th ESICUP Meeting will be held at HEC Building in the University of Liège. The building is located close to city centre and 15 minutes by walk from the train station.

Address:
Rue Louvrex 14, 4000 Liège


### REGISTRATION

The registration desk will be located in the meeting venue where you will collect your name badge and registration pack for the event. Registration will be open from 8.30am to 9.30am, May 4, 2017 and during session breaks.

### YOUR NAME BADGE

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

### NOTES ON PRESENTATION

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

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

**INTERNET ACCESS**
Further details on how to access wireless network at the conference venue will be given at registration.

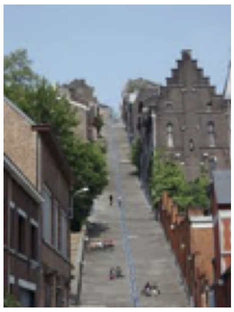
**DIETARY, MOBILITY AND OTHER REQUIREMENTS**
Please let the registration desk know if you have any additional special requirements.

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

**LUNCHES AND COFFEE BREAKS**
Two buffet lunches and coffee breaks will be held in local 138.

**CITY AND MOVING AROUND**

- **About Liège**
  As the most important tourist city in Wallonia, Liège has innumerable riches in store waiting to be discovered. The characteristic districts, the diverse topographical richness, the Meuse river and the wooded hills surrounding the city provide a multitude of original perspectives that give the city an exceptional charm.
  Liège is a very lively city with its cheerful population and its vibrant districts (the most famous ones are "Le Carré" and the Market place), the ideal places to have a drink and eat a typical dish. Tourists can also visit the old town centre, with "Hors-Château" and its dead ends, the "Saint-Barthélemy" collegial church and its baptism fonts, its "Perron" (symbol of Liège freedom) and Bueren Mountain with its 400 steps.

  In the 19th century, Liège was the heart of the Industrial Revolution in Europe and the coal and steel industries are a great part of its heritage. The House of Ironworks and Industry (museum) still allows its visitors to share a part of this heritage.
  Liège is also a shopping city with a dynamic commercial centre located in its pedestrian shopping streets and, each Sunday, with its market called "La Batte", the oldest Belgian public market and one of the most important in Europe.
  Like all Belgian cities, Liège is also famous for Belgian gastronomy, beers and chocolates which can be considered amongst the best of the world.

- **How to reach Liège**

  Liège is located in the heart of Europe, easily accessible by plane through Brussels or Charleroi (Belgium), Kölhn or Frankfurt (Germany), by speed train at Guillemins TGV train station and by car from Belgium's neighbouring countries

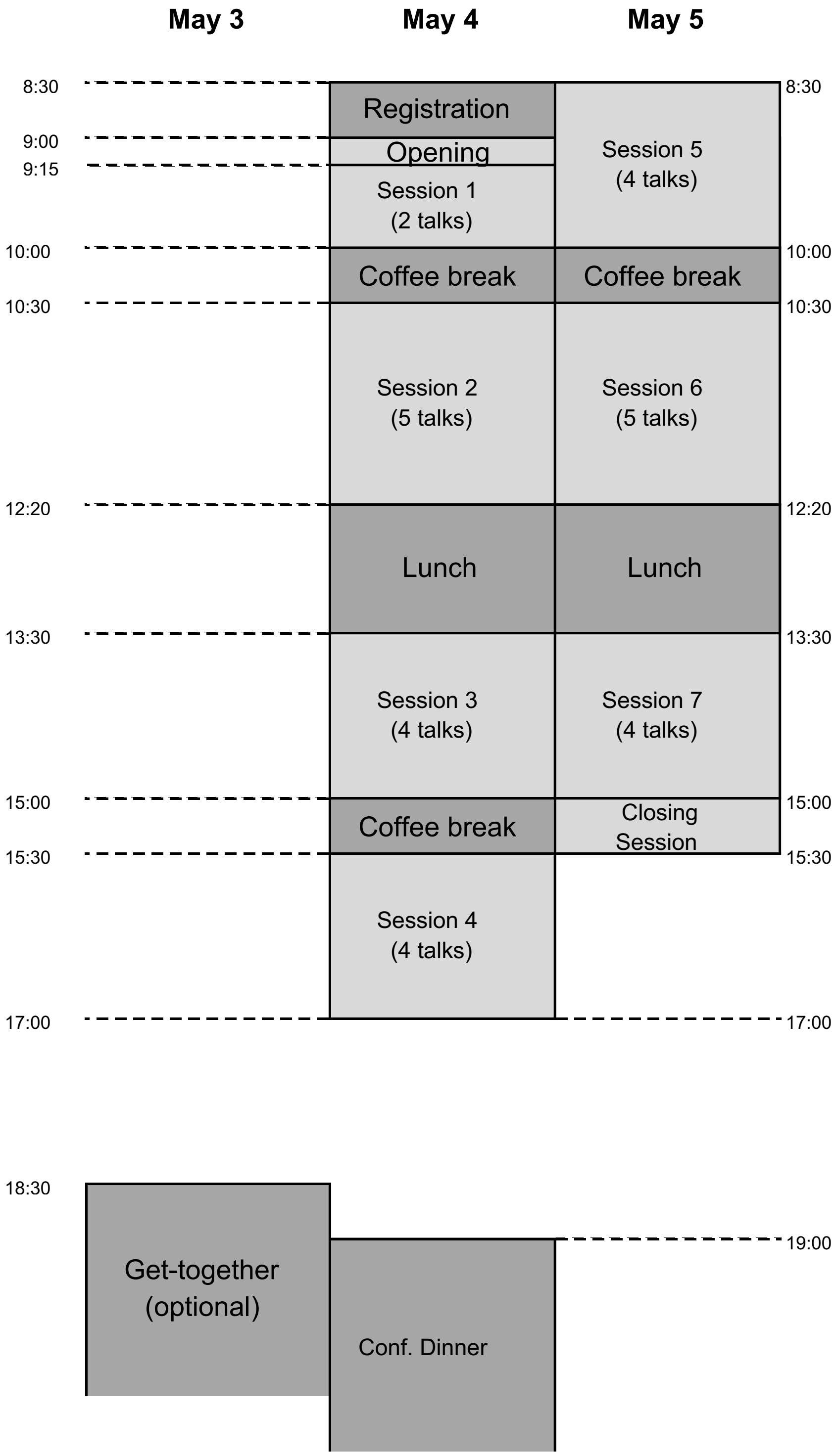
  - **By plane**
    Major airlines operate flights to Brussels Airport. Shuttle trains (Airport City Express) run every 20 minutes between the airport and several stations in Brussels. It is better to get off this train at the North Station in Brussels. This takes approximately 15 minutes. We advise you not to take a taxi from the airport to the North Station of Brussels because this is very

expensive ($\pm$ 25 EUR). If you want to take a taxi anyway, do not accept proposals made inside the airport hall, but use those parked in the official rank at the exit from the building. From Brussels North Station direct trains to Liège (Guillemins station) depart every 30 to 60 minutes, at least between 6:00 and 24:00. The journey lasts approximately 1 hour. Another possibility is to get off at Leuven Station and then take a direct train to Liège. Check the Belgian Railways web site for additional information and schedules. If you prefer to rent a car, several car rental companies have an office in the airport building at the exit of the luggage reclaim hall.
Low-cost airlines arrive at Brussels South Charleroi Airport. A public bus (Line A) links the airport to the Charleroi Sud train station. From there, direct trains to Liège (Guillemins station) depart every hour, at least between 6:00 and 23:00. The journey takes about 1 hour 15 minutes (`http://www.charleroi-airport.com/en/acces/en-train-bus/index.html`). Check the Belgian Railways web site for additional information and schedules.

– **By train**
Liège-Guillemins railway station is one of Europe's most impressive and beautiful stations, and is the work of famous architect Santiago Calatrava. Since it was opened in September 2009, Thalys, ICE and InterCity trains directly links Liège and its neighbouring countries: Germany (Aachen, Cologne, Frankfurt), France (Paris, Lille) and the Netherlands (Maastricht).

– **By road**
Liège is directly linked to the European motorway network through several motorways: from Brussels (E40), from Paris (E42), from Antwerp (E313), from Aachen (E40), or from Maastricht (E25).

# Program Overview



# Scientific Program Schedule

## Thursday, May 4th

**9:00 – 9:15**

**Opening Session**

Welcome Address

**9:15 – 10:00**

**Session 1** *Chair: José Fernando Oliveira*

*1.1* – A Beam Search heuristic for solving the heterogeneous multi-container loading problem
*J.A. Bennell, X. Zhao, T. Bektas, K. Dowsland*

*1.2* – A tailored two-phase constructive heuristic for the three dimensional Bin Packing Problem with practical constraints from an air transportation application
*C. Paquay, S. Limbourg and M. Schyns*

**10:30 – 12:20**

**Session 2** *Chair: Ramon Alvarez-Valdes*

*2.1* – Mathematical models for Multi Container Loading Problems with practical constraints
*Ramon Alvarez-Valdes[*], MariaTeresa Alonso[†], Manuel Iori[‡], Francisco Parreño[†]*

*2.2* – A GRASP algorithm for a multi-port container ship stowage problem
*Consuelo Parreño[*], Ramón Álvarez-Valdés[*], Francisco Parreño[†]*

*2.3* – The Container Loading Problem under intercontinental inventory constraints: A hybrid approach
*Elsa Silva[*], António G. Ramos[*†], Manuel Lopes[†], José F. Oliveira[*‡]*

*2.4* – A hybrid solution approach for the 3L-VRP with simultaneous delivery and pickup
*Henriette Koch, Andreas Bortfeldt, Gerhard Wäscher*

*2.5* – Multi-item, multi-vehicle dynamic lot-sizing problem with detailed loading constraints
*Martin Grunewald[*], Thomas Volling[†], Thomas S. Spengler[*]*

**13:30 – 15:00**

**Session 3** *Chair: Xiang Song*

*3.1* – A comparison between exact methods for 3D packing problems
*Everton Fernandes da Silva, Túlio Ângelo Machado Toffolo, Greet Vanden Berghe, Tony Wauters*

*3.2* – Packing of Polytopes within Spherical and Cylindrical Containers
*T.E. Romanova, A.V. Pankratov, Y.E. Stoian*

*3.3* – Multi-objective Build Orientation and Bin Packing of Parts in Selective Laser Melting
*V. Griffiths[*], A. Martinez-Sykora[*], J. P. Scanlan[*], M. H. Eres[*], P. Chinchapatnam[†]*

*3.4* – Layout optimisation for an installation port of an offshore wind farm
*Chandra Ade Irawan[*], Xiang Song[*], Dylan Jones[*], Negar Akbari[†]*

**15:30 – 17:00**

**Session 4** *Chair: Célia Paquay*

*4.1* – Real life constraints in load building
*Jelke J. van Hoorn, Christian Hutter, Lina Rahali*

*4.2* – Optimal packing of ellipses and ellipsoids
*T. Romanova, A. Pankratov, O. Khlud*

*4.3* – Solving the 2-dimensional heterogeneous bin packing problem with guillotine cuts
*M. Cabo**, *J. A. Bennell*†, *A. Martínez-Sykora*†

*4.4* – Metaheuristics for truck loading problems
*Ramon Alvarez-Valdes**, *Maria Teresa Alonso*†, *Francisco Parreño*†

# Friday, May 5th

**8:30 – 10:00**

**Session 5** *Chair: A. Miguel Gomes*

*5.1* – Height estimation for the rectangular two-dimensional strip packing problem
*Alvaro Neuenfeldt Júnior, A. Miguel Gomes, Elsa Silva, Carlos Soares, José Fernando Oliveira*

*5.2* – On Extracting a Combinatorial Structure in Packing Problems
*Oksana Pichugina**, *Sergey Yakovlev*†

*5.3* – Use and Reuse of materials in multi-period sheet cutting problem
*Ranga P. Abeysooriya, Julia A. Bennell, Antonio Martinez-Sykora*

*5.4* – Packing a limited number of unequal circular objects in a rectangular container
*Igor Litvinchev**†, *Daniel Mosquera*†

**10:30 – 12:20**

**Session 6** *Chair: Andreas Bortfeldt*

*6.1* – A column generation based heuristic for a sequential two-dimensional guillotine bin packing problem
*Quentin Viaud**†, *François Clautiaux**†, *Ruslan Sadykov*†*, *François Vanderbeck**†

*6.2* – Genetic algorithms to solve a constrained 2-d rectangle packing problem with applications in the vehicle ferry industry
*Christopher Bayliss, Christine Currie, Antonio Martinez-Sykora, Mee-Chi So, Julia Bennell*

*6.3* – Lower bounds and an exact approach for a bin packing problem with linear usage costs and precedence constraints
*Roland Braune*

*6.4* – A clique covering MIP model for the irregular strip packing problem
*Marcos Okamura Rodrigues, Franklina Toledo*

*6.5* – ~~Balance layout problems~~ (cancelled)
~~*I. Grebennik, T. Romanova, A. Kovalenko, I. Urnyaeva, S. Shekovtsov*~~

**13:30 – 15:00**

**Session 7** *Chair: Julia Bennell*

*7.1* – Solving the Air Cargo Palletization Problem by Logic-based Benders Decomposition
*Felix Brandt*

*7.2* – A meta-heuristic technique for the packing of three-dimensional irregular pieces
*Carlos Lamas-Fernandez, Julia A. Bennell, Antonio Martinez-Sykora*

*7.3* – Matheuristics for a real-world leather industry cutting problem
*Túlio A. M. Toffolo[*], Tony Wauters[*], Antonio Martinez-Sykora[†]*

*7.4* – A mixed integer linear programming approach for the recovery of unbalanced axle load distribution of cargo arrangements
*António G. Ramos[*†], Elsa Silva[†], José F. Oliveira[†‡]*

**15:00 – 15:30**

**Closing Session**

Closing Notes

# Social Program

- **Get-together Evening**
  May 3, 2017, from 18.30,
  La brasserie Liégeoise,
  Address: Rue des Guillemins 119, 4000 Liège
  Note: refreshments, snacks and meals available on a pay-yourself basis.

- **Conference dinner**
  May 4, 2017, from 19;00,
  Le Labo
  Address: Quai van benedden 20/22, 4020 Liège
  Three courses (starter + main + dessert), drink included.
  Fee included in the registration fee

# Abstracts

1.1

## A Beam Search heuristic for solving the heterogeneous multi-container loading problem

J.A. Bennell, X. Zhao, T. Bektas, K. Dowsland

*Southampton Business School, University of Southampton*

Our paper investigates the three-dimensional container loading problem with homogeneous and heterogeneous bins. According to the typology of cutting and packing problems, this is a cutting stock problem. The paper arises from a project with an industry partner who provides container loading software. The project aim is to investigate heuristic methodologies for extending the core packing algorithm over multiple heterogeneous containers. We present two heuristics; iterated local search and beam search, that solve the allocation of boxes to containers and determine the sequence boxes are packed into their allocated container. Our research examines different cost scenarios to examine the case for using different size containers. We introduce new benchmark data sets from industry to test the algorithms. Computational results indicate that while both approaches improve over current practice, beam search remains performs more consistently well.

**Keywords**: container loading, cutting stock problem, heterogeneous containers, local search

1.2

## A tailored two-phase constructive heuristic for the three dimensional Bin Packing Problem with practical constraints from an air transportation application

C. Paquay, S. Limbourg and M. Schyns

*University of Liege, HEC Management School*

The subject of this work is to solve the problem of packing a set of cuboid boxes into containers of various shapes without wasting loading space. There are few identical boxes and they all have to be loaded. As it is the case for all the packing problems, the packing has to satisfy geometry constraints: the items cannot overlap and have to lie entirely inside the bins. The richness of our application is to manage 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).

The aim of the method is to select the best set of ULDs to pack all the boxes achieving a minimum unused volume. In the literature, this problem is called a three dimensional Multiple Bin Size Bin Packing Problem (Wäscher, et al., 2007)).

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. In this purpose, a constructive heuristic has been developed. This algorithm is composed of two main phases. The first phase provides a loading pattern for a given set of boxes and a ULD type. Using sorting and selection criteria, a sequence of boxes is built and each box is packed one after another. The position selection is based on the Extreme Point (EP) designed for a packing problem with identical bins. The EPs represent the interesting possible positions to accommodate items. Several extensions are provided to consider all the constraints of the specific problem studied in this work. In practice, we have several types of ULDs that we can select, each type available in a determined quantity. Therefore, the algorithm has to be extended in order to take this possibility into account. The different types of proposed ULDs, which make the problem even more complex, and their selection represent the second phase of the algorithm, using the packing algorithm as a subroutine. It generates different loading patterns among which the pattern with the minimum volume or cost is selected and, if necessary, is enhanced in terms of weight distribution in a post process phase.

Along the algorithm, different criteria for sorting or selecting are used and several parameters require a tuning process. To make these choices, the software package IRACE has been used.

**Keywords**: bin packing, transportation constraints, extreme points

## 2.1
## Mathematical models for Multi Container Loading Problems with practical constraints

Ramon Alvarez-Valdes*, MariaTeresa Alonso†, Manuel Iori‡, Francisco Parreño†
* *University of Valencia,* † *University of Castilla-La Mancha,* ‡ *University of Modena Reggio Emilia*

In this paper we address the multicontainer loading problem of a distribution company that has to serve its customers by putting first the products on pallets and then loading the pallets onto trucks.
We approach the problem by developing and solving integer linear models. In order to be useful in practice, the solutions have to consider three types of constraints:

- Geometric constraints, so that all pallets are completely inside the trucks and do not overlap
- Weight constraints, limiting the total weight a truck can bear and the maximum weight supported by each axle, as well as some limits on the position of the centre of gravity of the cargo
- Stability constraints. Static or vertical stability is ensured because the pallets are put on the truck floor, but dynamic or horizontal stability has to be enforced by imposing specific constraints.

On the one hand, some constraints prevent empty spaces between pallets, to avoid cargo displacement when the truck is moving. On the other hand, excessive differences between the heights of adjacent pallets have to be avoided to prevent a tall pallet tipping over a short one. Several alternatives to control these differences in height are studied and their relative advantages are discussed.
We have also studied an extension of the model to the case, appearing frequently in practice, in which the demands have to be served over a set of periods. Two alternatives have been studied and compared in terms of flexibility and computational complexity. The models have been tested on a large set of real instances involving up to 46 trucks and kindly provided to us by a distribution company.
The results show that in most cases the optimal solution can be obtained in short running times. Moreover, when optimality cannot be proven, the gap is usually very small, so high quality solutions are obtained for all the instances tested.
**Keywords**: container loading, integer programming, optimization, single stock size cutting stock problems

## 2.2
## A GRASP algorithm for a multi-port container ship stowage problem

Consuelo Parreño*, Ramón Álvarez-Valdés*, Francisco Parreño†
* *University of Valencia,* † *University of Castilla-La Mancha*

The multi-port container ship stowage problem consists in developing a plan for the position of the containers in a ship taking into account its whole route and the different sets of containers that must be loaded at each port. More specifically, we study the simplified, purely combinatorial problem in which stability, weight, and other specific conditions are not considered. The objective of the problem is to minimize the number of unproductive moves necessary to unload the containers at their port of discharge. We assume that all containers are of the same size, the container ship consists in a single bay with $R$ rows and $C$ columns, and the ship's route is composed of $N$ ports.
In this paper, we propose a preprocessing phase taking into account all transportation information available. It works as a look-ahead mechanism that fixes certain containers liable to be moved unproductively. Our algorithm doesn't assign all the containers, for this reason we need to complete the solution using one of the heuristics presented in Avriel et al.(1998) or Ding and Chou (2015). Moreover, we present a local search technique based on the assumption that configuration of containers in port 1 has an important effect in the final plan. In this port, we select two different columns and exchange an homogeneous subset of containers belonging to the first column with another subset of same cardinality, but not necessarily homogenous, of containers belonging to the second one. After the exchange between columns, the solution is completed with one of the constructive algorithms. Finally, a GRASP algorithm has been proposed whose construction phase uses an existing constructive algorithm with some randomization strategies we have developed. So as to reduce the computational time invested in local search phase, we consider in this phase a modified version of the local search procedure presented previously.
In order to assess the relative efficiency of the algorithms, we implemented the algorithms in C++. Our test bed consist of two sets of instances in which the Transportation Matrices are randomly generated for full loading stowage planning problems. On the one hand, we generated SET I following the parameters proposed by Ding and Chou(2015) composed of a total of 625 instances, in which $N$ varies from 4 to 12, $R$ varies from 6 to 10 and $C$ varies from 50 to 250. On the other hand, SET II is composed of a total of 840 instances and it was generated looking for instances with solution greater than zero in most cases. In SET II, $N$ varies from 4 to 16, $R$ varies from 6 to 12 and $C$ varies from 2 to 12.
The computational study carried out corroborates the good performance of GRASP. Although in small problems all methods work fine, for bigger problems GRASP obtains better solutions. The computational study shows that

GRASP generates stowage plans with a minimal number of reshuffles in a high percentage of instances.
**Keywords**: stowage problem, heuristics, grasp, local search

2.3
## The Container Loading Problem under intercontinental inventory constraints: A hybrid approach

Elsa Silva*, António G. Ramos*†, Manuel Lopes†, José F. Oliveira*‡
** INESC TEC, † CIDEM, School of Engineering, Polytechnic of Porto, ‡ Faculty of Engineering, University of Porto*

This work addresses a case study in an intercontinental supply chain. The problem emerges in a company in Angola dedicated to the trade of consumable goods for building construction and industrial maintenance. The company in Angola sends the replenishment needs to a Portuguese company, which takes the decision of which products and in which quantities will be sent by shipping container to the company in Angola.
The replenishment needs include the list of products that reached the corresponding reorder point. The decision of which products and in which quantity should take into consideration a set of practical constraints: the maximum weight of the cargo, the maximum volume the cargo and the financial constraints related with the minimum value of purchases that guarantees the profitability of the business and a maximum value associated with shipping insurance.
To deal with the problem we propose a 2 stage hybrid method. In the first stage an integer programming model is developed to select the products that maximize the sales potential. In the second stage a Container loading algorithm is used to effectively pack the selected products in the container ensuring the geometrical constraints, and safety constraints such as weight limit, static stability and load balance. If a feasible solution can not be achieved with the products selected in Stage 1 the volume constraint in the integer linear programming is updated and a new iteration begins, the method ends when all the selected products are packed in the container.
A new set of problem instances for the problem was generated with the 2DCPackGen problem generator, using as inputs the data collected in the company. Computational experiments were conducted and the results will be presented.
**Keywords**: inventory planning, container loading, load balance
*The first author is grateful to FCT – Fundação para a Ciência e Tecnologia (Portuguese Foundation for Science and Technology) for awarding the Post-doctoral grant SFRH/BPD/98981/2013.*

2.4
## A hybrid solution approach for the 3L-VRP with simultaneous delivery and pickup

Henriette Koch, Andreas Bortfeldt, Gerhard Wäscher
*Otto-von-Guericke-University Magdeburg*

A vehicle routing problem with three-dimensional loading constraints and simultaneous delivery and pickup is introduced (3L-VRPSDP). Sets of different three-dimensional (cuboid) items have to be delivered to customers. At the same time, items have to be picked up from the customer locations and brought to the depot. This approach requires the integration of three-dimensional packing problems into the VRP with backhauls so that packing constraints such as stability requirements or LIFO constraints can be considered.
In order to solve the underlying routing problem, we propose an Adaptive Large Neighbourhood Search which is combined with different packing procedures to ensure the feasibility of the obtained solutions with respect to the packing subproblem. The solution approach was tested for newly generated instances for the 3L-VRPSDP and well-known instances form the literature for the one-dimensional VRPSDP. The corresponding results will be presented.
**Keywords**: vehicle routing, packing, delivery and pickup

2.5
## Multi-item, multi-vehicle dynamic lot-sizing problem with detailed loading constraints

Martin Grunewald*, Thomas Volling†, Thomas S. Spengler*
** Institute of Automotive Management and Industrial Production, Technische Universität Braunschweig, † Department of Economics and Business Administration, Fern Universität in Hagen*

We consider the multi-item, multi-vehicle dynamic lot-sizing problem with detailed loading constraints. Such problems are characteristic to companies which operate direct links between hubs as part of their supply chain

to transport loads with heterogeneous physical dimensions and fluctuating demands. Given knowledge on transportation demands, companies can save transportation costs by shifting load from future days to fill inflexible vehicle capacities. This will, however, imply holding and the corresponding costs. The problem is to determine a shipping plan which minimizes transport and holding costs while complying with capacity constraints. Former approaches consider the truck capacity only aggregated (e.g. maximum volume or weight). Beside a high standardization of load carriers in industry there are a lot of incompatibilities between load carriers. This is due to different length and widths, maximal bearing loads and different types of foot and shoulder of load carriers. This is illustrated by the case from the automotive industry which we consider. The selected direct link features approximately 300 parts boxed in 60 different load carriers with specific dimensions and stacking constraints. Therefore, we interpret the problem as an extended version of the Single Stock-Size Cutting Stock Problem and formulate it as a mixed-integer linear program. A heuristic rolling-horizon procedure is proposed that decomposes the problem into a container loading and a lot-sizing problem. We test the proposed procedure on some random problems which resemble the considered case from the automotive industry. The results show promising potential. As compared to day-by-day planning and two benchmarks with aggregated capacity models from the literature, truck utilization can be increased highly at a low increase of inventory level. Furthermore the benchmarks with aggregated capacity models lead to no appreciably increase of the truck utilization but to enormous increase of inventory level. The economic analysis with different cost rates for trucks and holding shows that cost savings are possible under a wide range of operating conditions and mostly independent of the shipping volume. The largest potential exists for mid- to long-distance transports. There is a relevant potential to improve short-distance transports as well, however, only if holding costs are moderate.
**Keywords**: multi-item dynamic lot-sizing, container loading, automotive industry

## 3.1
## A comparison between exact methods for 3D packing problems

Everton Fernandes da Silva, Túlio Ângelo Machado Toffolo, Greet Vanden Berghe, Tony Wauters
*KU Leuven*

3D cutting and packing problems arise when a set of items must be allocated inside one or more larger items. This problem's fundamental constraints require boxes to completely fit inside the container and to not overlap. A set of additional constraints can also be considered, namely: box rotations, weight limits, container stability and distribution, complexity constraints and loading priorities.

3D packing problems can be divided into categories according to their objective, one category concerns minimizing the number of containers employed while another involves maximizing the value of boxes placed in a container. This study addresses the first objective via the single stock-size cutting stock problem (SSSCSP), the single bin-size bin packing problem (SBSBPP) and the multiple bin-size bin packing problem (MBSBPP). The single large object placement problem (SLOPP) and the single knapsack problem (SKP), meanwhile, are variants for which this study addresses the second objective. There is another category which arises when a container does not have all of its dimensions fixed: the open dimension problem (ODP).

No recent study comparing all exact methods for 3D packing problems currently exists. Therefore, the aim of this work is to provide a thorough comparative study of the most significant exact methods proposed in the literature described. The compared methods include six mixed integer programming (MIP) models, three of which are taken from the multiple container literature, two from single container literature and one final from the open dimension variant. A combinatorial branch-and-bound for the multiple container problem is compared against the MIP models.

The basic premise is to adapt the selected methods, thereby enabling a proper comparison using classic benchmark datasets from the literature concerning the addressed problems. The datasets consist of different settings of containers and boxes, and varying in demand, dimensions and shapes to enable the evaluation of the various methods in distinct situations. New generated instances using a 3D cutting and packing generator proposed in the literature are also employed insofar as testing the scaling behavior and influence of container occupancy in regard to each method's performance.

The number of feasible and optimal solutions found within the time limit, the average time required to find the optimal solution, average percentage of boxes not placed inside the container and the volume occupation of the boxes placed inside the container are parameters employed when analyzing the different methods. The obtained results detail which methods perform better for a specific problem settings. These results will aid in the generation of both future improvements for exact methods and also the development of new formulations and matheuristics for the considered problems.
**Keywords**: 3D cutting and packing

3.2

## Packing of Polytopes within Spherical and Cylindrical Containers

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The study focuses on the problem of packing a given set of arbitrary polyhedra allowing continuous rotations in a container of a minimal size (a sphere with a minimal radius or a cylinder with a minimal coefficient of homothety). Non-overlapping and containment constraints are described by means of radical-free quasi-phi-functions. This allows building a mathematical model as a nonlinear programming problem with a domain of feasible solutions that is described as a system of inequalities with smooth functions. The proposed solution strategy includes a fast algorithm for generating feasible starting points and the COMPOLY-S optimization procedure that reduces the nonlinear programming problem with a large number of variables and a large number of inequalities to a sequence of smaller size problems and smaller number of nonlinear inequalities. The COMPOLY-S procedure significantly reduces the computational cost (time and memory) and allows an efficient use of modern NLP-solvers for solving nonlinear programming problems.

**Keywords**: packing, polyhedra, continuous rotations, quasi-phi-function, mathematical model, nonlinear optimization

3.3

## Multi-objective Build Orientation and Bin Packing of Parts in Selective Laser Melting

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This paper presents a metaheuristic model for the three-dimensional rotation, bin assignment and bin packing of parts across multiple Selective Laser Melting (SLM) machines, with the aim of reducing the overall production cost.

Selective Laser Melting (SLM) is an additive manufacturing (AM) method, which creates metal parts by iteratively depositing thin layers of metal powder on a build platform and fusing the powder particles in each layer with a laser, until the part is fully formed.

The time required to build a part via SLM is directly proportional to the number of layers required, which in turn is dependent on the part's build orientation (i.e. which way 'up' the part is positioned on the build platform). The part's build orientation also determines the space it takes up in the SLM machine. Thus, to produce a batch of parts cost-effectively, each part must be orientated in a way that minimises the overall number of layers required, while allowing the batch to fit into as few machines as possible.

Additionally, in order to prevent significant distortion and potential failure during SLM, steep overhanging sections of the part must either be avoided or reinforced with sacrificial support structure. This incurs additional post processing and scrap material costs, and thus support structure and surface angles of the part must also be considered when selecting the build orientation.

Thus, we propose a variable neighbourhood search (VNS) algorithm to solve the above problem in two stages – firstly, we select the build orientation of each part, which is described by two angles of rotation; secondly, we vertically project a two-dimensional convex polygon of each part and solve a two-dimensional irregular bin packing problem (2DIBBP) to pack the parts into SLM machines.

The 2DIBBP is solved in two phases: first we solve the one-dimensional bin packing problem to assign parts to bins, secondly, we use a Mixed Integer Programming (MIP) model to place the 2D pieces inside each bin. We then perform a local neighbourhood search to improve the solution.

In the VNS, we propose three different strategies. The first strategy sorts the packed bins by non-decreasing part height, then, starting from the last bin, searches for new build orientations of parts assigned to that bin, re-packing the pieces and accepting the new solution if the overall height is decreased. The second strategy orders bins by non-decreasing volume of support structure, then starting from the last bin, searches for new build orientations of parts assigned to each bin, re-packs the pieces and accepts the new solution if the overall volume of support structure in the bin is reduced. The third strategy sorts the bins by non-increasing area, then starting from the last two bins, searches for new build orientations of parts assigned to each consecutive pair of bins, re-packing the pieces and accepting the new solution if the area inside the last bin has been reduced.

Finally, we present some computational results and evaluate the quality of each solution based on its overall production cost. The results will show the effectiveness of minimising the height of parts, support structure and the number of machines in reducing the overall cost of medium-scale production of dissimilar parts via SLM. Around 20 different problem scenarios will be tested. The proposed model is aimed particularly at SLM of aero-parts, however, this approach can be easily applied to other complex geometries and other AM methods such as Selective Laser Sintering (SLS) of polymer parts.

**Keywords**: selective laser melting, additive manufacturing, 3d packing, 2d irregular bin packing problem, variable neighbourhood search

3.4

## Layout optimisation for an installation port of an offshore wind farm

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This paper investigates a port layout problem, where the layout of an installation port for an offshore wind farm needs to be generated in an efficient way so as to minimise the transportation cost of main components of an offshore wind turbine within the port. Two mixed integer linear programming (MILP) models are established to configure the optimal port layout, where the shapes of subareas that need to be located in the port are rectangular with several possible dimensional configurations to select from and the shape of the port area can be treated as either a convex or a concave polygon. The MILPs can be solved to optimality for small-sized problems. Matheuristic approaches based on Variable Neighbourhood Search (VNS) and an exact method (MILP) are also proposed to find solutions for medium-sized problems. The methods are assessed using randomly generated data sets. In addition, the area of a proposed Scottish port is used as a case study. The results obtained from the computational experiments validate the effectiveness of the proposed matheuristic approaches.

**Keywords**: layout optimisation, offshore wind farm, matheuristic approach, VNS, MILP

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4.1

## Real life constraints in load building

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In practice, we encounter a wide variety of practical constraints that should be considered during the process of three-dimensional load building. These constraints often originate in the planning and handling process of the loaded items or in legislation. Typically, these constraints render a large portion of the previously feasible solutions infeasible, although the effect on the optimal solution often appears to be limited. This makes handling such constraints a tough challenge. Although these constraints are often extremely relevant in practice, some of them rarely appear in scientific literature, especially combinations of these constraints. We present an overview of the constraints we encounter in practice. Special attention is given to axle weight constraints and grouping constraints.

**Keywords**: container loading, pallet loading, practical constraints, load distribution, grouping constraints

4.2

## Optimal packing of ellipses and ellipsoids

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We consider the optimal packing problem of a given collection of nonequal ellipses into a container of minimal area. Minimising the area of the design container is equivalent to minimising trimloss. Our ellipse problem falls into the category of Open Dimension Problem. To describe non-overlapping, containment and distance constraints we derive phi-functions, adjusted phi-functions, quasi-phi-functions, adjusted quasi-phi-functions. We formulate the problem in the form of a nonlinear programming problem. Efficient algorithms are developed to solve the ellipse packing problem for different shapes of container (a circle, a rectangle, an ellipse), employing fast starting point and special local optimisation procedures. This allows us to search for "good" feasible and local-optimal solutions. We extend our methodology to ellipsoids. We provide computational results for both ellipses and ellipsoids.

**Keywords**: packing, ellipses, ellipsoids, phi-function, quasi-phi-function, mathematical modeling, nonlinear optimization, open dimension problem

4.3

## Solving the 2-dimensional heterogeneous bin packing problem with guillotine cuts

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We present a two-dimensional bin packing problem with guillotine cuts and heterogeneous bins. Bins, in this case, are rectangles of different sizes. Pieces are irregular convex polygons that can be freely rotated and reflected. The objective is to minimise the utilization of the bins while answering the question of whether it is worth having a mix of different bin sizes. We assume that we have a finite number of bin sizes, and for each size, we have an unlimited number of bins. Any solution approach must decide how to group pieces to be packed together, which bin type to use and the packing pattern for each subset of pieces assigned to each bin.
We have developed a beam search algorithm that takes into account the different bin sizes, and exploits the possibility of having a mix of bins. Beam search is a heuristic that uses a tree structure of nodes and branches. Each node represents a packed bin. In creating a node, we decide the type of bin that node should hold, then a constructive algorithm selects and places the pieces in the bin to generate a packing pattern. A local evaluation function will decide which of the created nodes to keep for each parent node. A clear candidate for this function is to focus on utilization. This will favour tightly packed bins, a decision that may end in the use of more bins with lower utilization at the end of the tree. In order to avoid this case, we need to consider that it may be worth sacrificing utilization at the early stages if this decision favours a more even distribution of pieces across the bins in the final solution. Thus new local evaluation functions need to be tested.
The global evaluation prunes branches by constructing and evaluating a complete solution, which also considers the different bin sizes we have available. We generate a complete solution using a constructive heuristic that packs one bin of each type at each level, deciding at each level which bin type to keep and repeating this procedure until all pieces are packed. As with the local evaluation, using a decision criterion that only takes into account the quality of a single bin, like utilization or absolute waste, may not accurately represent which branch will report the best results. Thus our criterion to select which bin size to keep must also take into account the unplaced pieces. Finally, to compare the solutions on each branch we focus solely on percentage of utilization. We compare our results with the case when only one bin size is available, thus investigating whether it is worth spending more computational time finding a solution that uses a mix of bin sizes.
**Keywords**: bin packing, heterogeneous bins, guillotine cuts, beam search

4.4

## Metaheuristics for truck loading problems

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In this communication we address the truck loading problem of a distribution company that has to serve its customers by putting first the layers on pallets and then loading the pallets onto trucks. All the products have a predefined placement in layers. A layer is an arrangement of items of the same product in rows and columns, forming a rectangle.
We approach the problem by using a metaheuristic scheme. In order to be useful in practice, the solutions have to consider five types of constraints:

- Geometric constraints, so that all pallets are completely inside the trucks and do not overlap
- Weight constraints, limiting the total weight a truck can bear and the maximum weight supported by each axle, as well as some limits on the position of the centre of gravity of the cargo
- Stability constraints. Static or vertical stability is ensured because the pallets are put on the truck floor, but dynamic or horizontal stability has to be enforced by imposing specific constraints.
- Order of the products depending on the day. The company sends the trucks with the products for the first day and adjusts its data for the next days taking into account last-minute orders or cancelations. The problem begins when a depot sends a set of orders for the upcoming days. For each day , the order consists of a list of products , with their required number of items for this day. The products have to be served that day, or before, but not later.
- Stackability or load-bearing constraints are introduced to avoid damaging the items at the bottom of the stacks. Each product has an index. An we can only put pallets of certain index above pallets of other index. We have a matrix of stackabiltiy.

In order to deal with all the constraints we adopt a mateheuristic scheme because solving exactly the problem is not possible. We developed a GRASP algorithm with a constructive phase in which a solution is built by adding a pallet at each step according to the information collected from the truck, a randomization strategy to obtain

diverse solutions in an iterative process, and an improvement phase. A ejection chain mechanism is included in order to create a more complex compound move in the improvement phase.
The algorithms have been tested on a large set of real instances involving up to 46 trucks and kindly provided to us by a distribution company.
The results show that in most cases good solutions can be obtained in short running times.
**Keywords**: container loading, grasp, metaheuristics, path relinking, single stock size cutting stock problems

5.1

## Height estimation for the rectangular two-dimensional strip packing problem

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In the two-dimensional strip packing problem, the aim is to pack a set of rectangular small items inside a rectangular object with one dimension fixed and the other free, while minimizing the object's dimension that is free. The small items must be positioned without overlapping each other and completely contained inside the object. This description fits the definition of cutting and packing problems and indeed the strip packing problem can be classified as an open dimension cutting and packing problem.
In this work a method for the estimation of the strip packing height generated by a local search changing the items sequence in a bottom-left-fill heuristic is developed. This value can be used as a reference by the heuristics as a stopping criteria. In the problem's version we are dealing with, items should be orthogonally positioned in the empty spaces available in the object and can be rotated. Regarding the type of cuts, it is considered the guillotinable version.
To estimate the strip packing height we resort to a set of variables that represent the instances characteristics, related to the items and object shape variation, inspired on the structure and parameters of problem generators available in the literature.
The bottom-left-fill heuristic was implemented in order to solve a set of 72000 randomly generated instances, considering a wide variation of the variables above mentioned. This set of solutions was used both to train the estimator and afterwards to evaluate its performance.
For the estimation, non-linear data mining approaches (i.e. multivariate adaptative regression splines and random forest) were adopted and applied to estimate the strip height for each instance, with the aim of understanding the relation between the instances characteristics and the results obtained by the bottom-left-fill heuristic with local search.
Computational experiments were conducted and will be presented.
**Keywords**: strip packing problem, open dimension problem, heuristics, local search, data mining
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5.2

## On Extracting a Combinatorial Structure in Packing Problems

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An informal statement of a typical packing problem (PP) is to pack a finite number of geometric objects in a domain, whereas both the packing objects and domain have a given shape and are characterized by placement parameters and metric characteristics.
A mathematical model of (PP) is to find the extremum of a function that depends on the placement parameters of the objects and the metric characteristics of the domain. Functional restrictions are pairwise non-intersection of the objects and their placement in the domain (non-overlapping and containment constraints).
Note that, typically, the metric characteristics of the objects are given and are represented as some tuples.
In this report, a new approach to a mathematical modeling of (PP) is presented that applies an optimization technique of projection and lifting. A core of this method involves constructing an equivalent reformulation of the original problem in a higher dimensional space as follows. On the one hand, we perform a kind of lifting considering the metric characteristics of the objects as variables. On the other hand, we wish to remain the new problem in the extended space equivalent to original. To achieve this, we form a system of additional constraints on these variables, which ensure their convergence to the original values when the problem is being solved.
For constructing the additional constraints, an application of a continuous representation approach, which yields ways of continuous representations of discrete sets, is recommended. For instance, for the (PP), these complementary constraints describe a combinatorial set of permutations of tuples and a polyhedral-surface approach is applicable to its analytic description.

In the case of the tuple consisting of one variable, the combinatorial set is a general permutation set which is representable as an intersection of a general permutation polyhedron and a hypersphere surface. Another way is determining the set as an intersection of surfaces. Such problems with one metric characteristic arise widely in packing of spheres, parallelepipeds, and other homothetic objects (they are objects obtained from one by a homothetic scaling).
Based on the above technique, various optimization algorithms, depending on a shape of the packing objects and domain, were developed and implemented. To illustrate the applicability of our approach, we present a number of mathematical models for practical problems of packing and results of a computational experiment.
**Keywords**: packing, projection and lifting, permutohedron, combinatorial model, open dimension problem

5.3
## Use and Reuse of materials in multi-period sheet cutting problem

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There has been extensive research on the two dimensional bin packing problem that has produced powerful and sophisticated algorithms to determine the arrangement of items across multiple stock sheets, usually to minimise the material waste. However, there is limited research that extends this valuable work to the broader context of manufacturing such as the procurement of material, inventory policies and production planning. Usually individual orders or the day's production will be cut from multiple stock sheets (bins) where different standard sizes are available. The procurement policy affects the purchasing decision; to order single standard sizes or multiple standard sizes. In practice, the cutting plan for a particular period may result in a partially packed bin, resulting in an offcut that may be stored and reused for the following orders. The overall benefit of using offcuts is a trade-off between the saved material and the additional effort that is needed to manage offcuts. In this paper, we investigate this trade-off considering a range of scenarios and policy decisions. Specifically, we consider the cost of inventory, material handling and waste based on the decisions of implementing the use and non-use of offcuts for single standard bin size and multiple standard bin sizes separately. We compare performance of four such policies at nine different levels of cost structures considering material prices, set-ups cost and labour cost.
We present a model of multi-period irregular bin packing problem with residual reuse. This study builds on earlier works to solve two irregular bin packing problem with homogeneous and heterogeneous bins. In order to conduct the analysis, we consider a multi-period problem due to its practical applicability. We assume the case where future demand quantity of items are unknown when the current order is being processed and the full demand of a certain period must be met within that period. The packing algorithm determines the cutting plan to meet demand, which may result in usable residuals. If the policy allows residual reuse, they can be stored for future use. When processing each order, we solve a heterogeneous bin packing problem to place irregular items in standard purchased bins as well as offcut bins stored in the warehouse. An iterated local search embedded with the traditional jostle heuristic is used to solve this specific type of irregular shape bin packing problem by designing a fast constructive algorithm to generate bin packing solutions.
Using this packing algorithm, we test the impact of a variety of policies around the retention and reuse of residuals and examine the cost sensitivity of each of these alternatives. The computational results identifies the lowest cost policy for each of the scenarios and we present a decision tree to support operational decisions in sheet cutting industries.
**Keywords**: multi-period 2D-irregular bin packing problem, residual reuse, production and procurement policies, sheet cutting

5.4
## Packing a limited number of unequal circular objects in a rectangular container

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A problem of packing unequal circular objects is studied. The circular object is considered as a set of points that are all the same distance (not necessary Euclidean) from a center. For example, depending on the norm used, the shape of a circular object can be a rectangle, an ellipse, a rhombus, an octagon, etc. It assumed that upper and lower bounds for the number of objects to be packed are known. The objective is to maximize the (weighted) number of objects placed into the container or minimize the waste. The container is approximated by a regular grid and the nodes of the grid are considered as potential positions for assigning centers of the objects. A large scale linear 0-1 optimization problem is then stated using the binary variables representing assignment

of centers of the objects to the nodes of the grid. Recursive packing allowing nesting circles inside one another is also considered. A family of valid inequalities is proposed to strengthening the formulation. Numerical results are presented to demonstrate efficiency of the proposed approach.
**Keywords**: circle packing, integer programming, large scale optimization

6.1

## A column generation based heuristic for a sequential two-dimensional guillotine bin packing problem

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Our aim is to solve the following two dimensional guillotine cutting problem. Given a list of rectangular items, and a given rectangular plate size, the objective is to minimize the number of bins used to pack all items. We consider four-stage restricted guillotine cuts. Rotation of the items is allowed. A particularity of the problem is that the list of items is partitioned in batches, which have to be processed in a certain order. For practical reasons, only the last plate used in a batch can be used to cut items from the next batch. According to the typology of Wäscher et al. (2007), the problem considered here is 2D-SSSCSP.
To our knowledge, real-world instances containing up to 15 batches and 400 items in each batch cannot be solved exactly using state-of-the-art methods. Our approach is to solve successively the sub-problems related to each batch. Each sub-problem is a variant of the two- dimensional guillotine bin-packing problem, where the objective function is modified to take into account the amount of material left on the last plate, as it can be used for the next batch. To solve each sub-problem, we use a meta-heuristic as well as a column generation based diving heuristic. It transpires from our computational results on real-world instances from the glass industry that better solutions are found with the latter heuristic (at the cost of a larger running time).
**Keywords**: two-dimensional bin packing, guillotine cut, Dantzig-Wolfe decomposition, column generation, diving heuristic

6.2

## Genetic algorithms to solve a constrained 2-d rectangle packing problem with applications in the vehicle ferry industry

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In this paper we introduce a genetic algorithm (GA) approach to solve a 2-d rectangle packing problem with loading constraints which are derived from the vehicle ferry industry. We assume that the rectangles to be packed have a fixed orientation and are being packed into a fixed area. In this approach rectangles are packed sequentially in either a complete row or a complete column. Once a row (column) has been filled, it is removed from the remaining space. A solution of the GA is the sequence of rows and columns that generate the packing solution and the set of rectangles that are to be packed within each of them. When packing a column, the rectangles waiting to be packed that fit within the remaining space are sorted in order of width. For a row the rectangles are instead sorted by length. The GA selects a rectangle from the ordered list and continues to select rectangles above and below it in the list alternately until the column (row) is full. If a rectangle does not fit, the GA will move to the next rectangle in the sequence. The width (length) of the widest (longest) vehicle sets the width (length) of the column (row) and the dimensions of the remaining space are reduced accordingly.
The advantage of the proposed approach is the intuitiveness and ease of implementation of the solution for the target application–that of vehicle ferry loading. On vehicle ferries, vehicles are directed to parking spaces by human loaders and a solution based on filling complete columns or rows is easier to implement than a general 2-D packing solution. Vehicle ferries tend to load vehicles in lanes if this is possible; however due to the variety of vehicle types transported by our commercial partners, this is not always feasible or efficient (e.g. a wide vehicle may take up space from 2 lanes and a narrow vehicle may require less space). As a result a 2-d packing solution is beneficial and the proposed GA provides a 2-d packing solution that is implementable in practice.
Before vehicles are loaded onto the ferry they arrive at the ferry terminal in a random order. The dockside has a yard made up of parallel lanes that vehicles are directed to on arrival, where the type of the arriving vehicle is used to select which dockside queue to add it to. During the ferry packing procedure vehicles are loaded sequentially and the choice of which vehicle to load next is restricted to those which are at the front of yard lanes. We formulate the complete vehicle ferry loading problem as a two-stage stochastic optimisation problem with a first stage consisting of finding a dockside lane allocation policy that maximises the feasibility of the subsequent packing problem. The second stage recourse problem is performed online and resolves the packing problem for a realised yard configuration and is solved using the genetic algorithm. Simulation-based optimisation is used to solve the first stage problem.

We demonstrate the packing efficiency of the algorithm by comparing with lower bounds obtained by considering different relaxations of the problem. The GA is also tested in instances based on real observations.

**Keywords**: packing, genetic algorithm, uncertain arrival order, two-stage stochastic problem, policy optimisation

6.3

## Lower bounds and an exact approach for a bin packing problem with linear usage costs and precedence constraints

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The subject of this contribution is a bin packing problem with a non-standard objective and precedence constraints. The problem initially originates from a real-world multiprocessor scheduling problem where one of the objectives is to minimize resource idle time in the nearest future. The scheduling problem involves unit length activities of predefined size that are linked by chain-like precedence constraints with minimum and maximum time lags. According to the typology of Wäscher et al. (2007), we are given a weakly heterogeneous assortment of small objects to be allocated to identical large objects. While this would normally point to a cutting stock-like problem, the precedence constraints preclude a corresponding formulation. The bin packing representation of this problem is thus characterized by linear bin usage costs which increase with the bin index. While bin packing problems with more general linear usage cost (LUC) objectives have already been investigated (Cambazard et al., 2013), the actual objective function at hand in conjunction with the highly specific precedence constraints has not yet been addressed so far.

First, we show how lower bounding schemes known from standard bin packing can be modified to fit the considered LUC objective, with a focus on bounds L2 (Martello and Toth, 1990) and L3 (Labbe et al., 1991). The adaptations are non-trivial and cause additional computational effort. We are further able to prove worst case performance ratios for these two bounding schemes in the LUC context. Apart from that, we propose two new lower bounds, one based on a relaxation of a bin covering problem and the other one based on a multiple choice knapsack problem. Although all of the developed lower bounds rely on a relaxation of the precedence constraints, we are able to experimentally show their tightness also for the original problem.

Second, we embed the lower bounds into a branch-and-bound algorithm that is built upon the bin-completion scheme and thus feasible set-oriented branching. While dominance criteria for feasible sets known from standard bin packing can be shown to hold for the relaxed problem, this is not the case for the precedence-constrained variant. This makes the quality of the lower bounds even more crucial for the effectiveness and the efficiency of the branch-and-bound algorithm. Fortunately, the precedence constraints can be exploited for increasing the bound quality based on partial solutions, i.e., when some chains of items are already in progress. In the final computational study, we compare the branch-and-bound algorithm to industrial MIP and CP solvers (IBM ILOG CPLEX and CP Optimizer), since existing approaches to bin packing with LUC objective cannot handle the precedence constraints. Based on randomly generated benchmark instances that are inspired by the real-world problem setting, we are able to achieve optimal solutions in a fraction of the time taken by the general-purpose solvers.

**Keywords**: linear bin usage costs, precedence constraints, multiprocessor scheduling, lower bounds, branch-and-bound

6.4

## A clique covering MIP model for the irregular strip packing problem

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The irregular strip packing problem consists in the cutting of a set of two-dimensional pieces from an object of fixed width using the minimum possible length. Despite its economic importance for many industries, few exact studies have addressed this problem. Recently, a mixed integer programming model in which pieces are placed on a grid has been proposed. Although the model has proved the optimality for some large instances, it has a large number of non-overlap constraints, which grows quickly according to the discretization resolution and number of distinct pieces. This paper proposes a clique covering model to reduce the number of constraints and improve the linear relaxation. The model has outperformed the previous model in most evaluated instances and obtained an optimal solution for instances with up to 25 pieces (22 distinct pieces) subject to grid discretization.

**Keywords**: cutting and packing, irregular strip packing problem, clique covering, mixed integer programming

6.5

## ~~Balance layout problems~~ (cancelled)

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Layout optimization problems have a wide spectrum of practical applications. In particular, these problems arise in space engineering for rocketry design.
The paper studies the optimal layout problem of 3D-objects (solid spheres, straight circular cylinders, spherocylinders, straight regular prisms, cuboids and tours) into a container (a cylindrical, a parabolic, or a truncated conical shape) with circular racks. The problem takes into account a given minimal and maximal allowable distances between objects, as well as, behavior constraints of the mechanical system. We call the problem the balance layout problem (CBLP). We provide a mathematical model, taking into account combinatorial properties of the CBLP problem. We also consider several subproblems of the CBLP problem; construct appropriate mathematical models and develop solution algorithms, using continuous and discrete optimization methods, illustrated with examples.
**Keywords**: layout problems, behavior constraints, phi-functions, quasi-phi-functions, mathematical model, combinatorial properties, optimisation algorithms

7.1

## Solving the Air Cargo Palletization Problem by Logic-based Benders Decomposition

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The Air Cargo Palletization Problem (APP) is a container loading problem with many additional constraints stemming from physical, regulatory, or organizational requirements of the air transportation context. The objective is to load a set of strongly heterogeneous boxes into different types of trapezoid bins, called Unit Load Devices (ULD), while minimizing the penalties of not-loaded boxes along with the effort and cost of loading.
In this talk, we give an overview of the practical relevant constraints, stakeholders, and objectives and define the APP formally. We present our solution approach, which is a Logic-based Benders Decomposition of the problem. The master problem is a vector container loading problem. It decides, which ULDs to use and how to assign boxes to ULDs. Our sub problem is a 3-dimensional knapsack problem. It deals with the placement of boxes inside the ULD with respect to geometric, weight distribution, stackability and stability constraints.
For cases, in which not all boxes can be loaded in the sub problem, we derive valid inequalities (Benders Cuts) and add them to the master problem before resolving it. We repeat this process until all ULDs can be successfully loaded in the sub problem. Furthermore, we reduce the search space heuristically to make the problem solvable within an acceptable time limit. The master problem is solved as a MIP with Gurobi and the sub problem is implemented as a constraint program with Gecode running a heuristic non-exhaustive search.
We give an overview of our implementation and the evaluation of our approach with booking data of around 500 real world and artificial flights. Our experiments show that considerable improvements to the current manual palletization practice are possible, with respect to packing density, loading effort, and loading cost. Besides that, our approach also performs well in scenarios with highly utilized flights or short connection times of the boxes – features that make the APP more difficult in practice.
**Keywords**: air cargo, constraint programming, container loading problem, Logic-based Benders Decomposition

7.2

## A meta-heuristic technique for the packing of three-dimensional irregular pieces

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The 3D irregular strip packing problem consists in placing a set of irregular pieces in a container of a fixed base, with the objective of minimising its height. This problem, not very often studied in the literature, has a wide range of applications in 3D printing, packaging or component layout, among others.
According to the cutting and packing typology this is a 3D irregular open dimension problem. To solve it, we choose a discrete representation of the geometry that uses voxels, the three-dimensional equivalent of pixels. In this discretised space, we define the no-fit voxel. This is an extension of the two-dimensional no-fit polygon, a very popular tool used in two-dimensional packing. The no-fit voxel can be pre-calculated and allows us to very

quickly evaluate intersections of pieces during the algorithms and provides a complete description of the valid relative positions between two pieces.
Using this tool, we propose a meta-heuristic algorithm that allows overlap of pieces in its intermediate steps. It consists of two components, a search phase and strategic oscillation. In the search phase we perform a number of piece movements and swaps with the aim of resolving the overlap and finding feasible solutions. In the strategic oscillation, we increase or reduce the height of the container depending on the status of the layout.
We test this technique across a range of different instances. We adapted some instances from the existing literature, both two and three-dimensional. To deal with more complicated shapes, we also propose two other sets of instances. The first one consists in shapes randomly generated by ourselves by adapting 2D image generation algorithms. The second set consists in collections of parts of realistic objects taken from 3D printing websites. Our results show that this is a robust technique that can be successfully applied to find dense packings across pieces with very different features, regardless of their geometric attributes.
**Keywords**: 3d irregular packing, open dimension problem, voxel, meta-heuristics

## 7.3
## Matheuristics for a real-world leather industry cutting problem

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This work considers a leather industry cutting problem. The addressed problem, referred to within the literature as nesting in terms of category, is a two-dimensional cutting (and packing) problem where irregular and non-convex pieces of material must be cut from the hides. The goal is to minimize the amount of wasted material incurred during the cutting of such pieces.
In the specific context of the leather industry, it is not only the patterns which are irregular, but also the hides from which they must be cut. Additionally, hides often contain holes and different quality zones due to bites, scars and other imperfections. Some patterns require high quality leather while lower quality may be acceptable for others. Therefore, the permitted quality zones for each pattern are predefined, thereby imposing additional constraints.
Nesting problems such as the leather industry cutting problem are very relevant in practice, but the quantity of research dedicated to them is low when compared against other (more classical) cutting and packing problems. Previous researchers in the area have highlighted that this is primarily a result of the inherent difficulty involved in the implementation of the necessary geometric algorithms.
The present work formulates the leather industry's nesting problem as a mixed-integer program. A geometric toolbox (in Java) to robustly calculate no-fit polygons was developed. All problem characteristics are addressed, such as quality zones and holes. The resulting formulation, however, cannot be solved by state-of-the-art solvers when real-world instances are considered, stimulating the investigation of heuristic alternatives. The present research considers both constructive and local search (math)heuristics employing the proposed formulation. Different strategies and parameters are evaluated with regard to both performance and quality, and the obtained results are compared against the state-of-the-art in the literature.
Finally, to encourage further nesting problem research, the source code of the developed geometric toolbox (in Java) will be made available online.
**Keywords**: integer programming, matheuristic, nesting, leather, no-fit polygon
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## 7.4
## A mixed integer linear programming approach for the recovery of unbalanced axle load distribution of cargo arrangements

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With an expectancy of an increase of 55% by 2050 the continuous increasing volume of goods to be transported is challenging the economic, environmental and social efficiency and sustainability of today's supply chains. The current low occupancy rates of trucks, the amount of kilometres travelled by empty trucks, and the drivers' long periods away from home are putting pressure on transport companies to find better solutions.
These problems have been addressed in the academic literature within the classes of vehicle routing problems and container loading problems. Even though these problems have received a lot of attention they still do not meet the requirements of transport companies, due the large amount of practical relevant constraints, which have a strong impact on the determined solutions.

In this work, we address the axle weight distribution constraint, one of the least studied constraints present in road transport. The load balance between axles in road transport relates the distribution of the weight of the loaded vehicle among its axles and wheels and the limits they can withstand as to assure transportation in safety conditions. It is intimately related with the position of the centre of gravity of the loaded cargo and the weight limits of the axles imposed by regulatory and technical requirements.

Based on load distribution diagrams, that relate the position of the centre of gravity along the longitudinal or transversal dimensions of the vehicle with the admissible weight of the cargo we propose a MILP that, given a vehicle and a cargo loading arrangement, balances the axle weight distribution by moving and removing boxes in the cargo transport unit.

**Keywords**: transport, container loading, vrp, load balance

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# Notes