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An information system for the furniture industry to optimize the cutting process and the waste generated

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Abstract

Due to the current European economic stagnation and to face the increasing competition from emerging economies, significant changes in the European furniture industry need to be undertaken. Several institutions have produced reports showing that the European furniture industry must innovate the products, the production processes, the promotion strategies and the organizational structure in order to attain flexibility and productivity. The most relevant factor for the decrease in market share in the European furniture industry is the production cost, mainly due to labour and raw materials costs. The proposed information system aims to reduce the waste of raw materials generated in the production process, optimizing their purchase and consumption, boosting corporate profitability and sustainability.

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1. Introduction

Currently, the Western Europe forest-based industry is facing a fierce competition from emerging economies, such as, China, Brazil and some European countries in the former Eastern Bloc (e.g. Poland, Czech Republic and Romania). The main factor affecting the competitiveness of the Western Europe's furniture industry is the production cost, mainly due to labour and raw materials cost. On the other hand, Eastern Europe presents some characteristics (e.g. lower labour cost, qualified workforce, large forest resources and proximity to emergent

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markets) that are changing the Western Europe's furniture industry with an increasing number of imports from Eastern Europe of lower-priced raw materials and semi-finished components and an increasing number of production units transferred to Eastern Europe. Another observed phenomenon is the consolidation of the European furniture industry into larger units (through the merger or acquisition of production units) to face the growing market share of worldwide countries in this sector. This consolidation and the increasing investment in automation and computerization by some leading enterprises are compromising the sustainability of smaller enterprises. The growing importance of emerging economies in the forest-based industry and the stronger policies for legal and sustainable wood products drove several European organizations to release reports and outlooks[1–4] focusing the profound structural changes that this industry must perform in order to face these new challenges and opportunities. The main conclusion of these reports is that this industry must enhance competitiveness through product quality and design, increasing productivity and innovating processes, products, organizations and promotion in order to face the new market trends.

This industry is changing drastically, forcing the need for a more flexible but efficient production process to face the diversity of product's demand and market trends. Technology can play a fundamental roll in this context, mainly by providing high reductions of production costs and increasing competiveness and productiveness. The annex to the Strategic Research and Innovation Agenda[5], released in 2013 by the Forest-based Sector Technology Platform, presents some required research and innovation activities, such as, "*Use information and communications technology (ICT) to meet highest process efficiency, improving material flow, resource efficiency, process stability, machine productivity, etc.*" and "*Design new decision support systems for the optimal utilization of recovered material of used wood and paper products*". When technology is mentioned in this industry, people instantly think in new machinery and equipment but, as can be seen, information technology must also be considered. From the Strategic Research and Innovation Agenda for 2020[2], we highlight the following observation "… *current manufacturing and processing technologies use far more resources than is theoretically necessary. Technologies that radically reduce specific energy* and *material consumption have to be developed* …" which is the main driver for this project as it aims to provide an information system for the optimization of purchase and consumption of raw materials in the furniture industry. The objective of this information system is to answer to this new paradigm providing a tool that allows the reduction of production costs while increasing enterprises' flexibility and productivity.

The target industry of this project is the cluster of furniture enterprises in the Portuguese North Region, which is mostly composed by family-owned small and medium-sized companies, with fragile strategic planning procedures, no information systems to support their daily activities and no Research and Development departments. In this industry it is natural that when submitted to the cutting process, the raw material is not fully used, producing material losses. These losses raise the need to think carefully about the cutting plans to be executed in order to minimize the costs that result from the waste created. This problem is best known in the literature as the Cutting Stock Problem (CSP).

This paper is organized as follows. Section 2 introduces the CSP and in section 3 an overview of this project is presented. In section 4, we present the results accomplished by our information system in terms of waste reduction. In the last section, we present some conclusions and further research.

2. The Cutting Stock Problem

The Cutting Stock Problem (CSP) considers the existence of two groups of data, namely, the stock of available objects and the set of items that is intended to be obtained from those objects. The result expected when solving this problem is a cutting plan that consists of cutting patterns, wherein the items are allocated to objects. The residual parts (figures that occur in patterns that do not belong to the set of items) are considered losses, commonly referred as trim loss. The wide variety of cutting stock problems that can be found led some authors to create typologies in order to aggregate these problems by their common characteristics. For example, the typology introduced by Dyckhoff[10] classifies the problems considering four main characteristics (dimensionality, kind of assignment, assortment of large objects, assortment of small items). Wäscher *et al*.[11] improved this typology presenting a new categorisation criterion to deal with some "*severe drawbacks*" found in the Dyckhoff's typology.

The first CSP formulation was presented by the economist Kantorovich[6] and since Gilmore and Gomory[7] presented the Delayed Column Generation for the One-dimensional CSP (1DCSP), the interest for this type of problems has been growing due to its wide applicability (as a critical activity in the production planning in several industries such as metallurgy, textile, papermaking, glass and furniture) and its computational complexity (NP-Complete[8]). In 1991, Sweeney and Paternoster[9] categorized more than 400 publications directly related with this problem. The survey by Cheng *et al.*[12] shows that it is possible to find in the literature a wide variety of approaches for the solution of the CSP, which include exact methods[13], metaheuristics[14] and hybrid algorithms[15]. More recently, with the intent to heavily reduce the production costs, the use of retails (leftovers) in the generation of cutting plans has been the researchers focus. In 2014, Cherri *et al*.[16] wrote a survey about the literature approaches to solve the CSP with usable leftovers dividing them into three main sections: not based on mathematical programming models, item allocation oriented and cutting pattern oriented modelling.

3. Information system overview

Due to the current economic situation, enterprises must heavily reduce their production costs to increase their competiveness. This cost reduction can be achieved through a better use of raw materials but also at inventory management level "… *acting at the inventory level the results may present a wave effect through the production process. In brief this wave effect might be presented as lower quantity purchases that leads to less capital requirements, less warehousing needs, and less overhead costs*."[17].

This project intends to develop an information system that optimizes the use of raw materials, addressing in an integrated manner two critical phases of the raw materials management: the materials procurement and the use of these materials in the production environment. The integrated view of these two phases is crucial to obtain a global optimization. The inclusion of a cutting simulation component at the planning stage of materials acquisition and the method to solve the problem that arises from the cutting process, comprise the main innovation factors of this project. This information system is expected to achieve: better use of raw materials, more efficient stock management, economies of scale and better planning and forecasting of future needs. Another goal consists in obtaining an external integration with suppliers (and customers) that allows the selection of the best suppliers of raw materials taking in consideration input and output inventory levels. There are systems that seek to improve and streamline the purchase processes and the relationship with suppliers and there are also extensive research approaches in terms of algorithms and systems for advanced production planning. Nevertheless, Mendes *et al.*[18] concluded that there is still no information system that considers the optimized cutting process of raw materials, or optimally use them as the basis for the selection of the materials to purchase from suppliers, and therefore achieving an integrated model that seeks a global reduction of production costs and materials storage.

The proposed information system has several working modes, from acting as a component in an existent enterprise information system to acting as a stand-alone application with several levels of integration within the remaining, usually fragmented, information systems that the enterprises may have. This is possible as it is divided into a set of integrated components in order to achieve the maximum level of flexibility and extensibility, connecting all the processes, from the client order request to the cutting plan execution. At the core of this information system resides the main component which is responsible for the creation of optimized cutting plans.

It was estimated through direct observation of the targeted industry, that the waste of raw materials, for some materials, ranges between 15% and 25% mainly due to the cutting process. A wide variety of situations were identified in our target industry that must be clarified in order to understand what type of cutting problems will be solved by this information system:

- The objects in stock are rectangular wooden plates. The items to be extracted from those objects and that will be used in other processes are also rectangular;
- The objects considered when generating a cutting plan are all of the same material and may have different dimensions (except the thickness);
- The trim loss can be reused in future cutting plans' generation if its dimensions are within a value specified by the decision maker (those objects are classified as retails, while objects obtained directly from suppliers are classified as standards);

- The minimum width and height for a waste to be classified as retail varies according to each object's material type;
- Retails are classified as waste after a stocking period;
- When the object presents some kind of design, items can have a fixed orientation, while in other cases they can be rotated 90 degrees by exchanging their dimensions;
- Cutting machines only perform guillotine cuts and can, usually, cut the same pattern into several objects at the same time;
- The number of stages (object rotations) is restricted to 2 or 3;
- It is necessary to take into account the thickness of the cutting blade;
- Overproduction of items is not considered;
- There are not two enterprises alike, hence providing an algorithm to solve a problem with fixed objectives may not exactly represent the decision maker's intention;
- A problem involving a high-priced raw material can have very different objective(s) when compared to a problem with a lower-priced material.

Considering all the previous characteristics we have designed and implemented two multi-objective heuristics to solve the two-dimensional rectangular CSP with usable leftovers and guillotine constraints. Some parameters are previously defined by the decision maker, such as, the items' rotation and the number of stages (to provide higher flexibly we have not restricted this parameter).

Since production planning is a highly dynamic process (e.g. introduction of high-priority or cancellation of orders), the information system must be able to create efficient cutting plans very quickly, but must also provide tools for the decision maker to rearrange some of the items. This enables the creation of high quality cutting plans but it is more demanding on computational resources. After the cutting plan generation, it is possible for the decision maker to perform manual rearrangement of items, fixing their position on patterns. After this manual intervention a new cutting plan can be generated taking these decisions into account.

Taking this in consideration, two heuristics were implemented, namely, a Greedy Randomized Adaptive Search Procedure (GRASP)[19] and a Tabu Search[20] algorithm. The GRASP provides a way for a quick creation of cutting plans, while the Tabu Search aims to explore in a more intense manner the neighbourhood of the solution created by the GRASP in order to obtain solutions with a higher degree of quality.

GRASP is an iterative method that comprises two phases: 1) the Constructive phase that creates a solution using a randomized greedy procedure and 2) the Improvement phase that tries to improve the obtained solutions. Our constructive phase creates five cutting plans and is composed by two components that are identified as Randomized Greedy and Residual. The Randomized Greedy component aims to maximize the frequency of the patterns added to the cutting plan, in order to produce patterns with high percentage of occupied space. The Residual component ensures that all items not fulfilled by the previous component are fulfilled (hence we consider that standard objects have unlimited stock and that there are objects with a size greater than the size of all items). In order to maximize the use of retails in this phase, these two components iterate first over this type of objects (retails) and when no more patterns can be created or added to the cutting plan, the components iterate over the standard objects until there are no patterns that can be created and added to the cutting plan. In the Improvement phase, the (different) cutting plans generated in the Constructive phase are improved through a First Improvement Local Search procedure that uses four moves, namely, Merge patterns (creates a new pattern joining two patterns), Shift pattern (shifts an entire pattern to another object in stock), Shift shelf (transfers a shelf to another pattern) and Swap shelves (exchange shelves between patterns).

Tabu Search extends the concept of local search, allowing the exploration of different areas of the solution space and using memory structures to guide the search in order to allow intensification and diversification. The best cutting plan obtained by the GRASP heuristic is improved by the Tabu Search method using the following moves: Shift shelf, Merge patterns and Shift pattern, as already explained. The difference between this improvement method and the one used in the GRASP heuristic is that when the Shift shelf move is performed, the shifted shelf is considered tabu to prevent moving back to previous solutions. The tabu status of a move is not permanent; the number of iterations that must elapse in order to remove the move from the tabu list defines it. In our algorithms a move is considered tabu for the 25 following iterations. The aspiration criterion considers the objective function value, meaning that a tabu move will be executed if it leads to the best feasible solution found during the search. The Tabu Search method executes at most 1000 iterations or 250 consecutive iterations without improvement.

4. Preliminary results

As previously stated, the targeted industry usually does not have an information system to support their daily activities and therefore it is very difficult to obtain real data to evaluate the results of our heuristics. We also did not find any work in the literature that contemplates all the characteristics that we have in our heuristics in order to accommodate the situations observed in this industry (Section 3). This means that we are not able, at the moment, to compare our results with other solution methods.

Since real data and test instances from the literature are not available, we generated 100 randomly instances taking into account some characteristics of the targeted industry, and solved them with our heuristics to evaluate the results. The major characteristics of the generated instances are:

- The number of stages varies between 2 and 5;
- The number of standard objects varies between 1 and 4 (with unlimited stock);
- The number of retails varies between 25 and 50 with an associated stock that varies between 1 and 25 units;
- The number of items varies between 25 and 250 with an associated demand that varies between 1 and 30 units.

Since the decision maker can, in our information system, define multiple (conflicting) objectives using weights to express preferences, we have defined the following objectives to solve the generated instances: maximization of the average space occupied by items in a pattern, minimization of the trim loss, number of patterns, number of standard objects used and number of retails created. The value of the objective function is the sum of the weighted normalized objective values. The weights used for each of the objectives previously mentioned were 0.5, 0.2, 0.1, 0.1 and 0.1, respectively.

Table 1 presents the results obtained with our instances. The columns show the heuristic, the trim loss average, the average number of retails created, the average number of standard objects used, and the average time needed to solve the instances.

Table 1. Computational results.

Heuristic	% Trim loss	# Retails	# Standard objects	Time (s)
GRASP	4.1%	178	51	14.9
GRASP with Tabu Search	3.6%	186	51	75.0

From the analysis of this table, we consider that the results obtained in terms of trim loss reduction are very good. If the current state is considered, an average trim loss of 4% can provide this industry with very considerable cost reduction. Also, as observed in some enterprises, some raw materials are very expensive, hence any reduction of used objects or reutilization through leftovers can have a huge impact on production costs. With this in mind, we can verify that the Tabu Search heuristic can provide better results when compared with the GRASP heuristic, allowing a better reuse of the raw material with the same number of standard objects and producing 8 more retails and therefore reducing the average trim loss. The average computational time is acceptable considering the size of the instances generated.

The use of leftovers in production scenarios must consider a deeper evaluation of their real impact on all the supply chain and not as an isolated problem that does not influence the other productive processes. Since we intend to provide a flexible and extensible information system, some improvements must be implemented. These improvements, and also more conclusive results, will only be possible when we can access real data. At this stage we consider that the results are very promising in terms of raw material consumption.

5. Conclusions

We present an information system for the optimization of purchase and consumption of raw materials in the furniture industry. The main responsible for the waste generated in this industry is the cutting process and this information system aims to reduce this waste in an integrated manner. One of the most recent approaches to reduce the generated waste involves taking retails into consideration. These retails are leftovers from previous cutting plans executions that have returned to stock to be used to meet future demand.

The targeted industry has some particular characteristics, and from our observation, there are not two enterprises alike, hence requiring an information system that provides besides performance and good results, great flexibility. To generate the necessary cutting plans we have implemented two multi-objective heuristics to solve the two-dimensional rectangular CSP with usable leftovers and guillotine constraints. The first heuristic, based on the GRASP metaheuristic, allows the quick generation of cutting plans, while the second uses a Taby Search approach to further optimize the cutting plans.

The results obtained by our heuristics are very promising, since they make way for a significant reduction in production costs. Nevertheless, when dealing with real data, using retails introduces a higher degree of complexity that needs to be very well addressed, since they introduce logistic costs and can influence other production processes. The next step of this project is to evaluate the impact of our information system in the daily enterprise activities, in order to improve our heuristics and the overall performance of the information system.

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