Software Applications to a Real-World Cutting Problem of a German Wood Panel Manufacturer – A Case Study

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Abstract: This paper describes the solution of a real-world cutting problem of a German wood panel manufacturer. It gives an insight of the applied modern cutting technology, the resulting constraints of the cutting problem and the "soft" criteria for the user's assessment of the cutting software. Three commercial cutting programs are explicitly compared by their characteristics. Finally, a numeric comparison of the same software is carried out on the basis of 75 test instances randomly taken from the production process.

Key-Words: Cutting and Packing, cutting software, wood industry, cutting technology, optimization.

1 Introduction

Cutting & Packing (C&P) Problems are classic OR problems and are of high practical and scientific relevance. Publications on this issue accumulate rapidly in the last decades, although academic researches mostly concentrate on a confined number of abstracted problem types. We demonstrate in this paper the complex demand on C&P solutions in the practice, taking example of the cutting software demand of a German wood panel manufactory caused by the applied modern cutting technology. We also sketch the "soft" criteria for the solution quality, e.g. the possibility of result improvement by manipulation of calculated cutting plans.

After the characterization of the software demand, we come to investigate its counterpart, the supply – the available cutting programs. Two cutting programs designed for the applied technology and one program from a different application field are closely examined. Furthermore, all programs are tested with 75 problem instances taken from the production process.

Altogether, this paper compares the demand and supply of cutting software in one exemplary case and shows:

- which requests of real-world cutting problems must be satisfied by the software and how the applied cutting technology may influence the formulation of problem (constraints);
- which role the "soft" criteria of software quality plays within the assessment of a cutting program;
- which of the considered cutting programs at the market meets the specific requirements of a manufacturer and how far the level of suitability depends on the original domain or purpose of the cutting programs.

Section 2 starts with an introduction of the production process and of the general cutting problem, followed by a description of the applied cutting technology and the resulting constraints of the cutting problem. It also gives an insight of the "soft" criteria for the user's assessment of the cutting software. In Section 3, three commercial cutting programs are compared both by their characteristics and the numeric optimization results of 75 test instances. Finally, some conclusions are drawn in Section 4.

2 The demand on C&P software

2.1 The production process

The considered German wood panel factory engages some six hundred employees and produces a big variety of special fiber wood panels. Depending on their density, the panels may be divided in two classes, namely HDF (High Density Format) and MDF (Middle Density Format). The HDF panels have a density of 800-1050 kg/m³, and the MDF panels of 600-850 kg/m³. The HDF and MDF panels are commonly used as furniture back walls, filling material for doors, ceiling coatings, flexible walls or partitioning elements at exhibitions etc.

The production process of wood panels may be simplified as shown in Fig. 1.

The wood panels are produced out of row wood and glue, following the production procedures as specified below:

Row board production:

Wood fibers are mixed with glue, spread on a forming machine and later on pressed and trimmed into rectangular boards ("row boards").

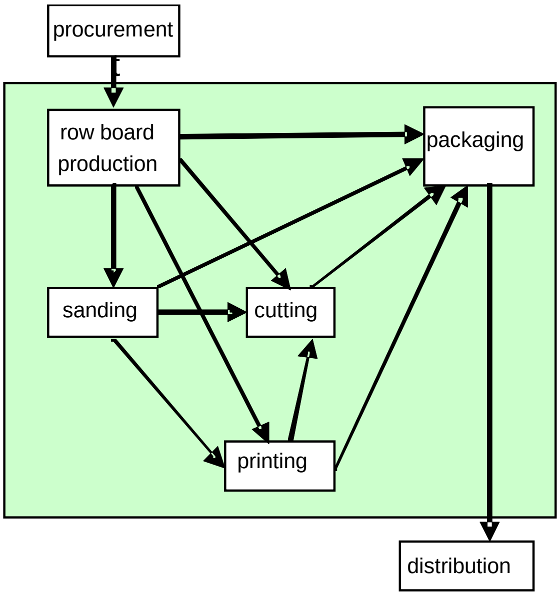

Fig.1 Production process of wood panels.

Sanding:

Through sanding (or *polishing*) the row boards receive a smoother surface.

Printing:

The (polished or unpolished) row boards may be printed with single colours or certain motives.

Cutting:

The boards are trimmed into given sizes on request of customers.

Packaging:

The panels have to be wrapped according to specific packaging instructions.

2.2 The cutting problem

All confirmed orders have to be produced. The suitable wood boards for the production of the panels are available in sufficient quantity and if not, immediately made. Thus, the cutting problem is in principle a pure input-minimizing problem.

The customers usually order a big quantity of rectangular panels that may be divided into a few classes according to material quality and sizes. Mostly one and, in some rare cases, two to three different sizes of big boards are taken for production of the ordered panels.

Using the typology of Wäscher et al. [1], this cutting problem is a 2-dimensional rectangular single stock size (or multiple stock size) cutting stock problem with guillotine cuts.

2.2.1 Objectives

The performance of the optimization algorithm is assessed by its accomplishable objective values. Several objectives come into question for the manufacturer:

1. minimizing the material input,
2. maximizing the material usage or minimizing the trim loss,
3. minimizing the production time, and/ or
4. minimizing the costs.

The first two objectives are equivalent, both aiming at efficient use of the limited material. We shall apply the trim loss criterion in the following examination of cutting software. The objectives 3 and 4 require the acquisition of detailed data from the production process and are therefore not considered.

2.2.2 Constraints

Regardless of the applied cutting technology, the following constraints must be met for the wood panel processing:

1. Production quantity: All ordered panels must be produced, while an overproduction is only allowed within a certain limit.
2. Orientation constraint: Some rectangular panels show printing motives and these may not be rotated, while for panels without printing motives a rotation by 90° is allowed.
3. Cutting thickness: Depending on the thickness of the saw blade, each cut has a certain thickness of its own. This thickness has to be taken into consideration for the optimization.
4. Trimming cuts: For a better edge quality, a trimming cut is taken on all four sides of the boards. The trimming cut has to keep a minimal distance to the edge. The minimum of space between the trimming cut and the edge is not necessarily identical on all four sides.
5. Guillotine cuts: Each cut has to be parallel either to the length or the width of the boards. Each cut reaches from one end to the other of the boards.

2.3 Applied cutting technology

The wood panel manufacturer possesses a variety of cutting facilities. An example of the applied modern cutting technology is the Schelling angular cutting plant built by the Austrian machinery manufacturer Schelling Anlagenbau GmbH. The plant covers the functions feeding, cutting, sorting, stacking and strapping. The wood boards are inserted into the cutting plant by the feeding device. The trimming saws cut the boards into given sizes according to the cutting plans. The ready cut panels are then sorted according to the size and subsequently stacked up. After they are wrapped and strapped according to packaging instruction, the panels are ready to be delivered to customers.

Based on the machinery functions, there are a number of "technology-driven" constraints to be considered in addition to those enumerated in Section 2.2.2.. For example:

Stack height:

The big boards are cut in stacks. As shown in Fig.2, the maximal stack height (p) – confined by the cutting range of the saw blade (s) – must not be exceeded. On the other hand, if the stacks are below a minimal height, they may be damaged by the panel pushers that direct them throughout the production process. Thus, there are altogether two constraints to be satisfied in this context: the maximal and the minimal stack height of the boards/ panels.

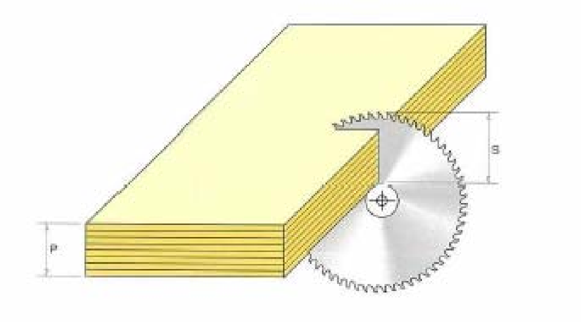

Fig.2. Maximal stack height.

2.4 "Soft" criteria

The manufacturer evaluates the cutting programs not only by the performance of their optimization algorithm. A number of "special performances" are expected of commercial cutting programs, for instance:

1. Possibility of solution improvement through manual manipulation.
2. Direct data connection between the cutting program and the ERP-program, so that the master data and order information don't have to be entered again for the optimization.
3. Direct data connection between the cutting program and the cutting facilities, so that the confirmed optimization results may be carried out automatically.
4. Short calculation time.
5. Easy-to-use graphic user interface.
6. Effective service package of the software provider.
7. Last but not least, a competitive price.

Unlike the "hard" criteria for the mathematic model, such criteria are relatively subjective and partially not quantifiable. Still, those aspects play an important role in the manufacturer's assessment of the cutting programs.

3 Cutting programs

Since the rectangular cutting stock problem is NP-hard, metaheuristics such as Simulated Annealing or Tabu Search are considered most suitable solution approaches nowadays. Faina [2] developed a Simulated Annealing Algorithm for 2-dimensional rectangular cutting stock problems. Lodi et al. [3] solve 2-dimensional bin packing problems with a Tabu Search Algorithm based on two neighbourhood types, while Faroe et al. [4] proposed a Guided Local Search procedure to solve 3-dimensional bin-packing problems.

Further methods that address rectangular cutting stock problems and related problems were proposed by Vanderbeck [5], Liang et al. [6], Onwubolu and Mutingi [7], and Hifi [8]. Further relevant references are gathered in Dyckhoff and Finke [9] as well as in Wäscher et al. [1]. Besides, a comprehensive bibliography by Coffman et al., especially for the C&P problem type bin packing, may be found in the internet [10].

Although the academic researches achieve fine results for (more or less) "pure" multidimensional rectangular cutting stock problems and/or bin packing problems, they do not address the specific demands related to the modern cutting technology and cannot be directly used by the wood panel manufacturer. The problem is to find an available cutting program that, if necessary through modification at acceptable expenses, addresses all the above-mentioned technical aspects of the cutting plant.

3.1 Commercial cutting programs

There is a large number of commercial cutting software offers. Many of them are specialized in a certain application field, which implies, that the programs most likely address the special demands in the specific field.

In this paper, we have chosen three cutting programs for closer examination. Two of them are specialized in industrial cutting of wood panels, whereas the other is tailored to metal sheet processing. Some of the major characteristics of the above-mentioned programs are put together in Table 1. The available model constraints of the programs have been proven by numerical experiments.

Evaluation criteria		C&P Programs: PCut	HPO/CutOS	ToPs 100
General characteristics	**Application field**	industrial cut-to-size saws for wood processing	industrial cut-to-size saws for wood processing	laser and water jet machining
	Form of big objects	rectangular	rectangular	rectangular
	Number of different big object formats	one or several	one or several	only one
	Form of small objects	rectangular	rectangular	any kind
	Cutting patterns	guillotine cuts	guillotine cuts	guillotine cuts when parts are rectangular
Objective function(s)	**Standard objective function(s)**	cost minimization, i.e. minimization of sum of material and production costs based on given internal cost rates	cost minimization, i.e. minimization of sum of material and production costs based on given internal cost rates	optimization of trim loss
Model constraints and further characteristics (detected through testing)	**Min./max. production quantity**	Generally no underproduction allowed. Level of acceptable overproduction adjustable.	adjustable, how strictly the constraints should be considered	strictly considered
	Panel stacking (min./ max. stack heights)	adjustable	adjustable	not considered
	Min. cutting thickness	adjustable	adjustable	adjustable (as min. distance between parts)
	Min. width of trimming cuts	adjustable	adjustable	adjustable
	Manual result manipulation	possible	possible	possible

Table 1 Comparison of cutting programs.

3.2 Numerical results

The three cutting programs have been subjected to a comparative numeric test. Since the optimization results often depend on the test instances, we used real-world test data and took 75 problem instances randomly from the production process.

The following constraints which always apply regardless of the used cutting technology have been taken into consideration for the test:

1. Min./ max. production quantity, 2. Orientation of the parts, 3. Cutting width, 4. Trimming cuts, 5. Only guillotine cuts.

For the test, the programs PCut and HPO/CutOS were adjusted to the cutting procedure of the angular cutting plant. They both satisfy the constraints described in Section 2.3. This was not possible with ToPs 100 due to too many differences in the original domain. Since the computation with ToPs 100 must be done in relation to a specific cutting facility, the laser machine Trumpf TC 600L with the control type 840D was chosen.

The programs are compared with respect to the trim loss rates in the test results, whereas overproduction is treated as trim loss. The performances of the tested programs are quite similar with exception of extremely poor results in some isolated cases. Such poor performances are normally easy to be detected and rectified by the human planner.

The average performance of the tested programs is shown in Table 2.

Calculated results	C&P Programs: PCut	HPO/ CutOS	ToPs 100
Average trim loss with one big object format (%)	13.04	12.83	14.35
Average trim loss with 2 or 3 big object formats (%)	10.40	13.54	–
Average trim loss of all test instances (%)	12.22	13.05	14,35
Average computing time (seconds per problem instance)	73	84	38
Frequency of computer used for tests (GHz)	2.8	2.8	2.8

Table 2 Average performance of cutting programs.

ToPs 100 doesn't work with more than one big object format, therefore there were no results calculated by means of this program for the problem instances with 2 or 3 big object formats.

For the wood panel manufacturer, it is important that the cutting software considers all technical conditions of the cutting facilities. From this point of view, *ToPs 100* is hardly his choice, since more than moderate program modifications would have to be made to suit his applications. Also the "soft" criteria play an important role in his view. An advantage of *PCut* is for instance the generation of plural solutions for each problem, making it easy for the planner to manipulate the results. One of the advantages of *HPO/CutOS* is that the user can easily match the technical adjustment to the cutting facilities through program parameter adjustment, while in case of *PCut* a programmer has to lay his hands on the task.

4 Summary

In this paper, practical requirements of C&P programs as they occur in the case of a German wood panel manufactory are analysed.

Due to the complexity of the real world problems, the academic C&P researcher usually concentrates on a few essential aspects. As applicable solutions to the industrial problems, however, C&P programs must consider the versatility of the problems. Many software producers answer to this requirement by specialization in a certain industrial application field. In the given situation, two specialized C&P programs turned out to be fully applicable to the manufacturer's C&P problems, whereas another C&P program tailored to another application field could only be applied to a certain problem type.

Some "soft" criteria which are critical for the user's assessment of the C&P solutions have also been discussed, although such criteria are relatively subjective and partially not quantifiable.

The assessment of cutting programs by their calculated material use has to consider that the results depend on the applied problem instances. Therefore, the used test instances have been randomly taken from the production process. They are, at least in some industrial application fields, relatively representative. As a support for practice oriented research, the problem instances and the test results obtained by the commercial programs are made available in the internet (see www.fernuni-hagen.de/WINF).

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