C&P Software for a 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:

C&P, cutting software, wood-working industry, constraints, cutting technology.

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1 Introduction

C&P problems 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 abstract 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, i.e. 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 fibre 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 for the following purposes:

- as cabinet back walls, drawer bottoms, filling material for furniture doors, etc.;
- as ceiling coatings, support panels for parquet floor, or as pressure distributor for carpet and other types of floors;
- as flexible walls or partitioning elements at exhibitions, one-sided or both-sided printed with wood or fantasy motives;
- as decks for almost all types of doors;
- as support for picture frames, decoration elements and sales installations etc.;
- as fittings in vehicles.

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

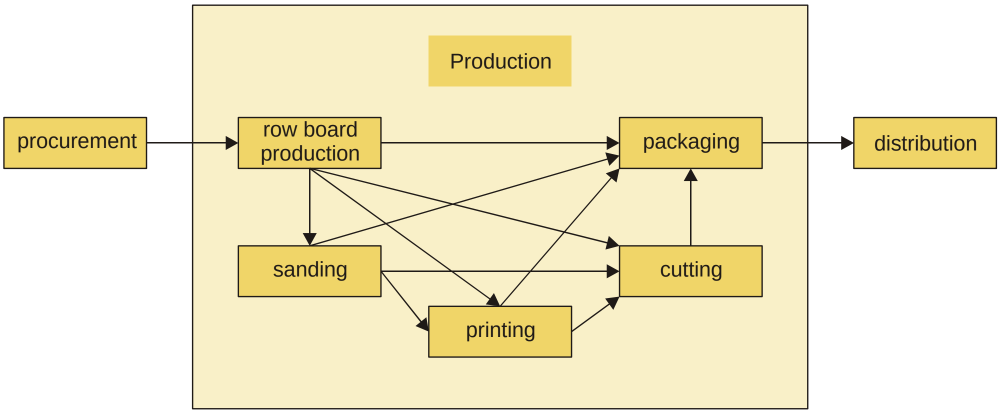


Fig. 1: Production process of wood panels.

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

Row board production

The production begins with chipping row wood and cooking the chips into fibres in a container (“*Refiner*”). The fibres are then mixed with glue, spread on a forming machine and later on pressed and trimmed into rectangular boards. The boards with untreated surfaces are called “*unpolished row boards”*.

Sanding

Through sanding (or *polishing*) the row boards receive a smoother surface. The products after sanding are named as “*sanding boards*”. The row boards may be polished on one or both sides.

Printing

The (polished or unpolished) row boards may be printed with single colours or certain motives. The features of colours and motives are determined by the clients with consideration of the limits of the printing machines. The row boards may be printed on one or both sides.

Cutting

The boards are not only available in standard production formats, but also in smaller sizes when demanded by the clients. By the “cutting” procedure the boards are cut into panels in required dimensions.

Packaging

The panels have to be wrapped according to packaging instructions. These instructions determine the details of packaging, e.g. the type and sizes of the pallets, the covering panels, the wrapping band, the corner protection, the wrapping foil, the number and height of panels per package etc.

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 minimization 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. (2004), this cutting problem is a two-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. They are quite common objectives in C&P problem solutions and demand no further explanations.

In fact, the wood panel manufacturer does not always prefer the solutions with the best material use, but sometimes those with shorter production time due to high expenses of manpower and the sophisticated machinery. In order to optimize the production time, constraints based on the production process and technical specifications of the cutting facilities have to be added to the C&P model (see Section 2.3 for details).

The objective minimizing the costs conforms to profit maximization. The costs of manufacturing may be divided into material costs and production costs. In contrast to the unproblematic declaration of material costs, the calculation of internal production cost rates is often disputable, mainly due to the problem of distribution of overhead costs. Using inaccurate cost rates may lead to poor performance of the cutting program. In order to avoid such problems, this objective may be equated with simultaneous optimization of material input and production time. However, the treatment of objectives 3 and 4 requires the acquisition of detailed data from the production process. Therefore, these objectives are not considered in this paper.

2.2.2 Constraints

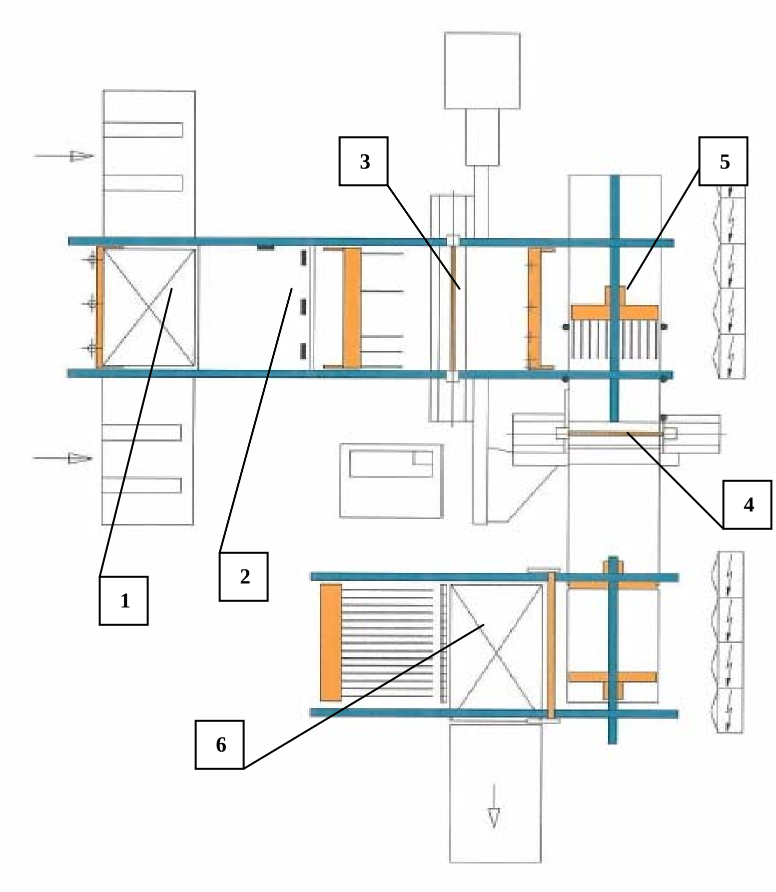
Regardless of the applied cutting technology, the following constraints must be met for the wood panel processing:

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 angular cutting plant has one rip-cut saw and one cross-cut saw. Each saw has a saw blade that moves within a linear track (see Fig. 2). The saw blades cut only in one direction and are driven back to the starting position automatically after each cut.



Legend:

1. Infeed
2. Turning device
3. Rip-cut saw
4. Cross-cut saw
5. Angular transfer
6. Automatic sorting/ stacking device

Fig. 2: Layout of Schelling Angular Cutting Plant.

Stack height

The big boards are cut in stacks. As shown in Fig. 3, 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 and panels.

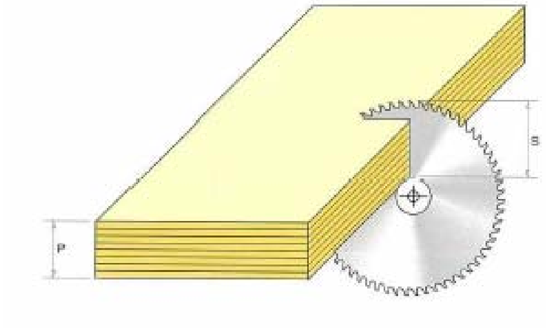


Fig. 3: Maximal stack height.

Panel grouping

The angular transfer is divided in two feeders. This enables the cutting plant to cut the panel stripes in two different widths in one pass (cf. Fig. 4 and Fig. 5). The bound between the panel groups has to lie within a certain area due to the machine construction.

Cutting style

The turning device can execute 90° turns. Therefore, the first cut may be taken either along the length or the width of the boards. This again results in two possible cutting styles: “with headpiece” and “without headpiece”. The styles are illustrated in Fig. 4 and Fig. 5; each sketch also includes a sample cutting pattern. By the cutting style “with headpiece”, after the “headpiece” has first been taken off, the residual piece is turned at 90° and processed in a similar manner as “without headpiece”. In other terms, the style “with headpiece” generates three-staged guillotine cutting patterns while two-staged guillotine cutting patterns are generated by the other style. The choice between the styles is a case-to-case decision of the human planner.

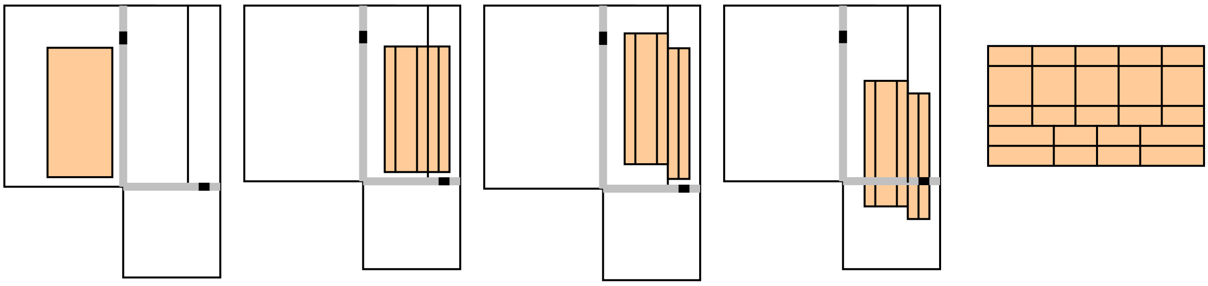


Fig. 4: Cutting style “without headpiece”.

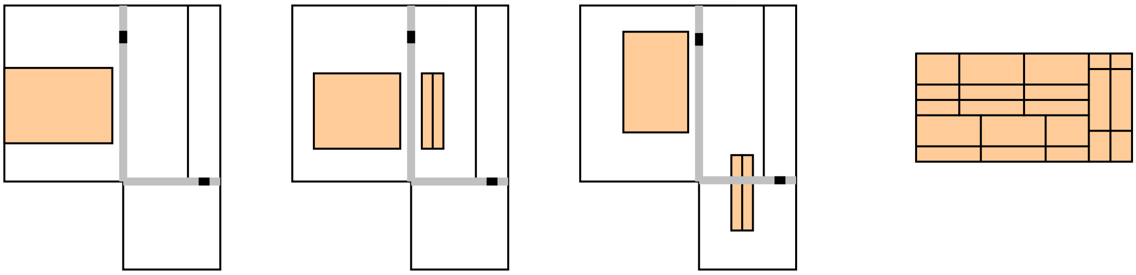


Fig. 5: Cutting style “with headpiece”.

Fixing of boards

During the cutting procedure, the panel stacks are stabilized by fixing clamps installed around the angular transfer area. Each stripe of a panel stack has to be grasped by a minimal number of clamps that depends on the width of the stack. The positions of the clamps have to be taken into account by the generation of cutting patterns. Moreover, too narrow panels will fall between the transfer rollers; therefore, there is another constraint concerning the minimal width of a panel.

Loading stations

After automatic sorting, the ready cut parts are transported to the loading stations. They will not be taken away for packaging, until the full amount of the same part has arrived. The number of loading stations is limited. This implies, both the number of different cutting patterns and the number of different parts in each cutting pattern should be kept under a certain level. Also the generated cutting patterns should be arranged in such a way that only a minimal number of loading stations are occupied.

The calculation of production time depends also on the cutting technology. The production time on the angular cutting plant for instance has several components:

1. Book building – preparing, inserting of the boards and clearing of the cut parts;
2. Cutting;
3. Time for the saw blades to drive back to the starting position;
4. Rotations of the boards and panels;
5. Sorting of ready cut panels;
6. Waiting time for further transport to packaging station.

The technical statement of the machinery manufacturer may serve as guideline for the calculation.

Industrial cutting is a continual procedure. The tact time on each station – feeding, cutting, sorting, stacking and strapping – should match each other. Thus, there is also a machine-loading problem to solve.

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 used, 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 (1999) developed a Simulated Annealing Algorithm for two-dimensional rectangular cutting stock problems. Lodi et al. (1999) solve two-dimensional bin packing problems with a Tabu Search Algorithm based on two neighbourhood types, while Faroe et al. (2003) proposed a Guided Local Search procedure to solve three-dimensional bin packing problems.

Although these methods 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. The available model constraints of the programs have been proven by numerical experiments. The major characteristics of the above-mentioned programs are put together in Table 1.

Evaluation criteria		**C&P Programs**		
		ProCut/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
	Producer	software producer	machinery producer	machinery producer
	Model development	proprietary development	development of others (Dresden University of Technology)	proprietary development
	Mathematical method	unknown	unknown	unknown
	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
	Number of different small object formats	max. 200	many	many
	Cutting patterns	guillotine cuts	guillotine cuts	guillotine cuts when parts are rectangular
	Cutting styles	with and without headpiece	with and without headpiece	no different styles
	Rotation of parts	90° rotations possible	90° rotations possible	adjustable, rotation step 1° upwards

Table 1: Comparison of cutting programs (part A).

Evaluation criteria		**C&P Programs**		
		ProCut/PCut	**HPO/CutOS**	**ToPs 100**
Objective function(s)	**Standard objective function(s)**	optimization of trim loss and production time	cost minimization, i.e. minimization of sum of material and production costs based on given internal cost rates	optimization of trim loss
Model constraints (detected through testing)	**Min./ max. production quantity**	not strictly considered	adjustable, how strictly the constraints should be considered	strictly considered
	Availability of big formats	yes	yes	yes
	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
	Max. number of different cutting patterns	adjustable	adjustable	not detected
	Max. number of loading stations	adjustable	adjustable	not considered
	Max. number of different parts per cutting pattern	not detected	not detected	not detected
	Fixing of boards	considered	considered	considered only for the removal of rest material (metal sheet)
Miscellaneous	**Number of optimization solutions**	max. 26 solutions possible	one solution only	one solution only
	Manual result manipulation	possible	possible	possible
	Direct data transfer from ERP program	possible	possible	not possible
	Automatic carry-out of optimization results on new cutting facilities	possible through program modifications	possible through parameter settings, but only applicable on self-made machinery	possible through parameter settings, but only applicable on self-made machinery
	Calculation speed	fast	relatively fast	very fast
	Straightforwardness of graphic user interface	high	relatively low due to thousands of parameter settings	high
	Program documentation	simple on-line help	not available for the many possibilities of parameter settings	simple on-line help
	Other program functions	-	-	optimization with all shapes of parts possible

Table 1: Comparison of cutting programs (part B).

3.2 Numeric results

The three cutting programs have been subjected to a comparative numerical 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. Minimal and maximal production quantity.
2. Orientation of the parts.
3. Cutting width.
4. Trimming cuts.
5. Only guillotine cuts.

The following identical data of the problem instances were used for the test runs with the chosen cutting programs:

1. Number of different formats of big boards;
2. Dimensions and available quantity per big board format;
3. Number of different part formats;
4. Dimensions per part format;
5. Minimum and maximum production quantity
   (min./max. number of parts per part format);
6. Orientation constraint per part format (90° turns allowed or not allowed);
7. Cutting width;
8. Width of trimming cuts.

For the test, the programs *ProCut* 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 test results are shown in the following graphics. Each point in the graphics stands for the calculation result of one problem instance. The problem instances are sorted in ascending order according to the total number of ordered parts. The solution quality of the programs is primarily assessed by the trim loss in the cutting plans.

Fig. 6 shows the computing results of 61 test instances with one big object format, the required total production quantity ranging from 206 to 22242 parts. Fig. 7 shows the results of 14 test instances with two or three big object formats, the total production quantity ranging from 668 to 27771 parts.

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

With respect to the trim loss rates, 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.

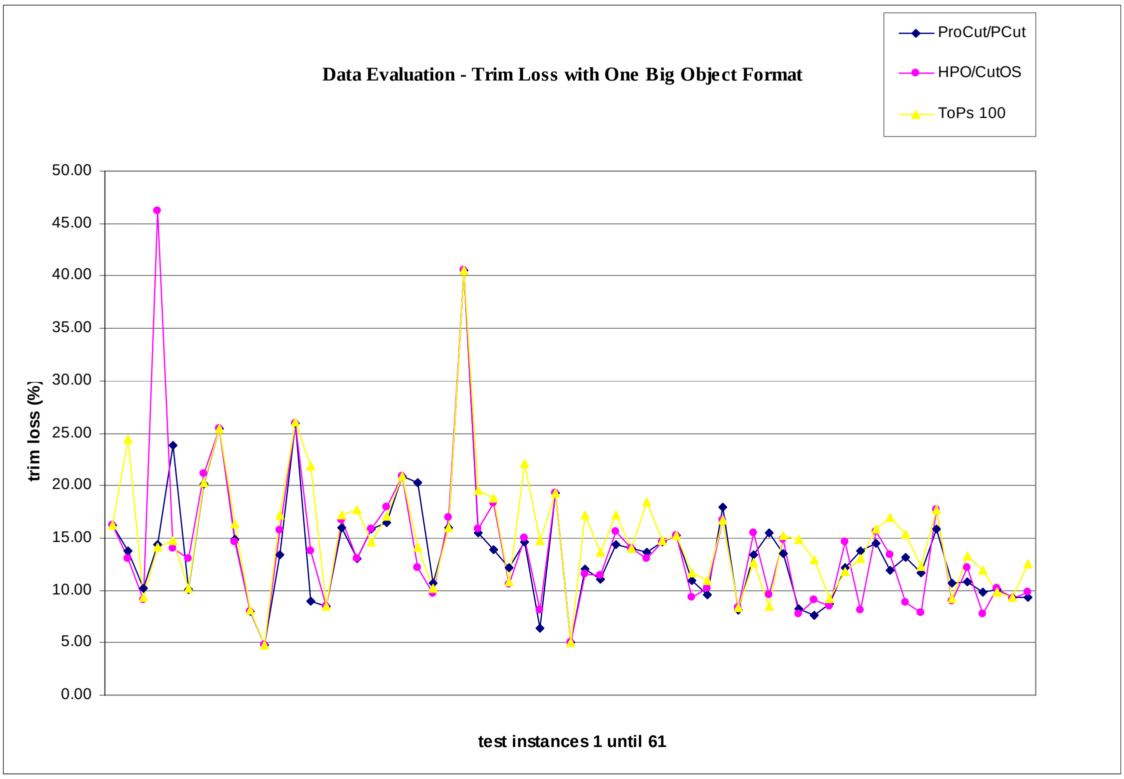


Fig. 6: Trim loss for 61 test instances with one big object format.

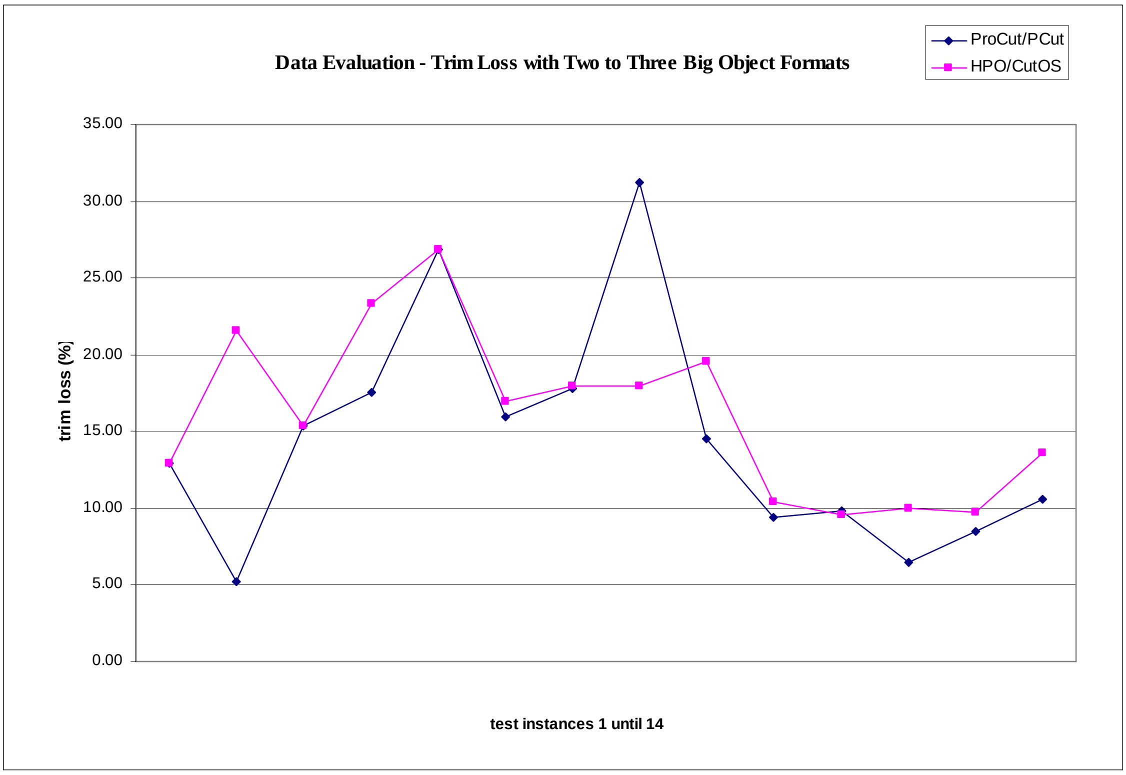


Fig. 7: Trim loss for 14 test instances with two to three big object formats.

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

Calculated results	C&P Programs		
	ProCut/ PCut	HPO/ CutOS	ToPs 100
Average trim loss with one big object format (%)	13.04	12.83	14.35
Average trim loss with two or three 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.

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 *ProCut/PCut* is for instance the generation of multiple 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 *ProCut/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 more generalized problem.

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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