Renovation of the Cutting Stock Process

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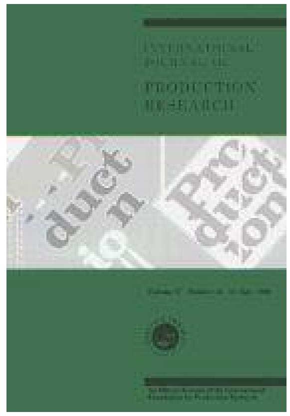

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Abstract

In the paper a new approach to the cutting stock (CS) problem as one of the activities in the CS process is proposed. A thorough critical review of the literature is conducted in order to identify the main limitations of the current state of research. The main finding is that the CS problem is treated too narrowly and that the connection of the CS process with other processes in a company, along with a better transfer of information, should be studied. The paper presents a methodology for evaluating CS process renovation benefits. A process flowchart technique is used to compare as-was and as-is states, while simulations are conducted to provide an estimate of the benefits and to compare the costs of trim loss with other production costs. A case study of a company involved in non-ferrous metal and iron retail activities is used to analyse the effects of renovation of the whole CS process that led to a considerable reduction of cutting costs and lead times. A decrease in the variability of the CS process lead time is also noted which can lead to the more standardised fulfilment of customers' orders. The measurement and reduction of costs can improve the competitiveness of companies that undertake cutting or similar (e.g. packing) operations in production.

Keywords: cutting stock problem; business process modelling; business process reengineering; business information systems; case study; simulation

1 Introduction

The cutting stock problem was first defined over 50 years ago and has since attracted relatively constant attention from researchers and practitioners. The problem frequently appears in the paper, textile, metal, electrical, pulp and other industries. Since the seminal paper in the 1960s (Gilmore, Gomory, 1961) several new methods for solving the CS problem have been developed – utilising either a pattern- or item-oriented approach (Gradišar et al., 1999a) and leading to either heuristic or exact solutions. Most of the state-of-the-art solutions lead to an optimal or near-optimal solution for large sizes of different versions of the problem with a given set of orders and a given stock in the warehouse.

However, in recent years it has sometimes been claimed that a simple improvement in the CS method does not necessarily lead to the improved efficiency of the CS process or increased competitiveness of the company or the supply chain as a whole. It has been shown that an instantaneous solution of the problem can even lead to considerably inferior results over a longer time period (Trkman & Gradišar, 2007). In fact, the improved methods for instantaneous optimisation that are presented in most papers only tackle a certain part of the issues connected with the CS process. The decrease in trim loss only involves part of the total cost connected with the preparation of desired quantities of order lengths.

The paper therefore treats CS as a business process in a company and presents a new approach to the optimisation of the CS process that enables a decrease in total cutting costs in given time period, the improved execution of the process and better achievement of the company's goals (e.g. decreased variability in lead times). In this way CS better contributes to the business goals of a company and not just to a reduction in the trim loss. The theoretical findings are supported with a case study of one of the largest retailers in the south-east of the

EU. The holistic treatment of the CS process also helps point out several under-researched areas that should receive greater attention in future research work.

The paper's structure is as follows: in the next section literature on the CS problem is critically reviewed. In the third section the importance of optimising CS as one of the processes in a company is analysed. In the next section an approach to CS process renovation is analysed through a case study. The main points and further important research areas are summarised in the conclusion.

2 The cutting stock problem – a literature review

Operations research methods and techniques are often used in production management. One of the significant fields is the CS problem where operation research can make an important contribution to the improved fulfilment of a company's objectives. The proper application of different exact or heuristic CS methods can considerably enhance the execution of the CS process. This means a reduced trim loss, shorter cutting times and lower costs.

The main problem is to cut the available material into the required order. The general definition of the problem is (Gass, 1985): The available material has a different length and width. The orders are given as the number of pieces of each order length or as a total length for each order. The usual goal is to distribute orders on different stock lengths to minimise the trim loss.

The growing number of different methods for solving the CS problem was the reason Dyckhoff (1990) proposed a system for their classification. While Dyckhoff's classification has been relatively widely used over the past decade and a half, a recently published classification (Wäscher et al., 2007) presents a considerable improvement in the organisation of the cutting and packing ('C&P') fields. It enables the classification of cutting goals (either input minimisation or output maximisation), but does not include the classification of the business objectives of the company. C&P is still quite traditionally oriented. It stresses areas which include clearly-defined (''classic'') standard problems that have been well studied for three decades or even longer. Still, (Wäscher et al., 2007) mainly point to the under-researched topics within the C&P and not to the broader approach proposed in this paper.

Most CS problems are NP-complete and an exact solution often cannot be expected within a reasonable time limit. Gilmore and Gomory's method (1961) presented the first efficient approach to column generation that only tested the most promising columns. In the following decades several efficient heuristic methods utilising either pattern- or item-oriented approaches have been developed – only the most important from recent years, are presented in this paper (see e.g. Wäscher et al., 2007 for a full review).

The heuristic method in (Yanasse & Limeira, 2005) minimises both the trim loss and the number of cutting patterns in order to decrease cutting costs. Only those patterns that have both low trim loss and low overproduction are taken into account when preparing a cutting plan. Yen et al. (2004) also take pattern changes costs into account. Similar to (Gradišar et al., 1999b) the importance of testing a large number of possible solutions was emphasised. Ghodsi and Sassani (2005) present a fuzzy-ranking method for real-time CS optimisation with prioritised orders. However, the overall scheduling of the production shop floor was not addressed. The importance of this is shown in our case and emphasised as an important future research topic. Although most studies focus on one-dimensional stock cutting, two and three-dimensional versions have also attracted considerable attention (see e.g. Cui, 2006).

The reusability of partly-cut material has been an infrequently used suggestion for a decrease in cutting costs (since Gradišar et al., 1997). The study of (Arbib & Marinelli, 2005) includes trim loss, quality, schedule and cutting preparation costs as the main criteria for a cutting plan. The partly used material can be stuck back together and reused later. It was shown that proper planning (taking weekly instead of just daily data into account) of the CS problem can reduce costs by 43%. Kos and Duhovnik (2002) also include the possibility of reusing remnants in subsequent optimisations. The acceptable sizes of remnants are user-specified, based on the production type and production planning. Similarly, Yang et al. (2006) defined an incentive trim loss –remainders over that limit do not count as a trim loss. Trkman and Gradišar (2007) highlighted the problem that the introduction of reusability can lead to the accumulation of partly used stock lengths in the warehouse unless the methods are adapted accordingly. The costs of storage and reuse of partly cut material should therefore be properly included in the solution method. Nevertheless, none of those papers studied the challenges posed to the CS problem by the introduction of the reusability of material. The approach in the 5th section enables an estimation of the reusability costs.

Since modern methods lead to results with a very low trim loss (e.g. Gradišar et al., 2002) further considerable reductions in trim loss are impossible – for example, the enhancement of the method in (Gradišar & Trkman, 2005) leads to a reduction of trim loss from 0.025% to 0.015% of available material – which is still a considerable improvement in the method yet a very small contribution in terms of reducing company costs. Similarly, Degraeve and Schrage (1999) presented a method that leads to an optimum solution in 3,984 out of the 4,000 examples of their version of the problem.

Therefore, the approach of researchers has moved slightly towards methods with mixed objectives (Trkman & Gradišar, 2003; Yang et al., 2006), which recognize that trade-off between different objectives (e.g. cutting time and trim loss) has to be considered in preparation of the cutting plan (Morabito, Arenales, 2000). Traditionally the main criteria for judging the appropriateness of the solution were: trim loss, overproduction, average inventory level, average number of different stock length and average number of stock lengths in the inventory (Venkateswarlu, 2001). Only the third criterion can be vaguely related to the business context of the CS problem, while all others only optimise a single activity in the process. Our approach therefore also includes the costs of equipment, work costs, lead times and their variability as important criteria for evaluating proposed solutions. Lead times and their variability are namely one of the most important parameters in material planning (Christensen et al., 2007).

Although the importance of the development, classification and usage of new cutting and packing optimisation methods should not be neglected, the savings from cutting process renovation are comparable to those in a trim loss reduction; as shown, the latter is generally getting lower over time. Further, Trkman and Gradišar (2007) highlighted the possible unsuitability of existing cutting methods when applied to optimisation over a longer time period and developed an approach to CS optimisation in consecutive time periods. They mentioned the possible applicability of the approach to cutting in a supply chain; however its practical implementation was not studied. Similarly, Gramani and Franca (2006) found that an optimal solution for the combined CS problem and lot-sizing problem probably contains non-optimal solutions for the CS and lot-sizing problems considered separately. Chauhan et al. (2007) offer interesting insights into different order penetration points in a paper supply chain. Although the importance of the study of lead times is mentioned, their method only deals with minimisation of the sum of inventory holding and trim loss costs.

As shown in this section, state-of-the-art methods for instantaneous CS optimisation lead to a near-optimal solution for trim loss minimisation. Therefore, a further improvement in CS methods alone cannot considerably improve the execution of production. A methodology for renovating the CS process and measuring its benefits is presented in the continuation of this paper.

3 Optimisation of a cutting stock process

Although it has been claimed several times that there has been an increase in the scientific attention and number of published papers in the C&P area (Gradišar et al., 1999a; Wäscher et al., 2007) it does seem that the number of papers in this field published in top-level journals remains relatively stable (as seen in Table 1), which could indicate the maturity of this field.

(Table 1)

The vast majority of papers on the CS problem appears in the main journals in the area of operations research. Although research on the CS problem has also appeared in journals from other disciplines such as Naval Research Logistics, the Journal of Intelligent Manufacturing and the Forrest Products Journal (Carnieri et al., 1993), studies of the CS problem as one of the manufacturing processes virtually do not exist. Further, while the emergence of supply chain management concepts have had a minimum influence on inventory theory (Buxey, 2006) its influence on the CS problem seems to be completely lacking. Therefore, most of the newly developed CS problem methods still demonstrate the main deficiencies of the quantitative approach identified almost 10 years ago (Fowler, 1998) – they are too abstract, culturally alien to many managers, while the models are too simplistic.

The CS problem methods also assume that complete and accurate information is available to the decision-maker. This is often not the case in practice because information flows in the company or a supply chain can be slow and incomplete (Trkman et al., 2005b).

Therefore, it can be stated that the CS problem research suffers from the often cited ‘relevance’ problem of operations management research – researchers do not address more practically relevant problems and the real-life needs of decision-makers. The relevance of observations in a practical setting is often not tested (Bertrand & Fransoo, 2002).

The treating of the CS problem as one of the processes in the company is in line with recent findings that organisations can enhance their overall performance by adopting a process view of business. It has been shown that companies, which have reached a higher business process maturity level consistently, outperform others (Lockamy & McCormack, 2004). In this section some of the papers that have moved slightly towards a ‘process improvement orientation’ (Burgess et al., 2006) of the CS problem are mentioned.

An interesting solution of the packing problem within the electronic industry is described in (Cochran & Ramanujan, 2006). The study highlights the interconnection of various decisions within a downstream supply chain, such as the choice of packaging and the inclusion of value-added services. Thus the best combination of options available to the manufacturer to reduce the overall cost has to be selected. Weng and Sung (2007) highlight that cutting optimisation is not enough – and that the whole procedure (Stock arrangement, Piece arrangement, Marking work, Cutting work, Delivering work) has to be optimised. The paper then presents a method for optimisation of the sum of the trim loss and work efficiency. Rodriguez and Vecchieti (2007) present an optimization of cutting problem in board boxes production process within the pulp and paper supply chain and the linkage of such solution to the ERP system of an organisation. Similarly, the role of CS in the paper industry is identified as only one of the decisions in production scheduling that consists of order allocation, formation and sequencing of batches, trimming, and load planning (Keskinocak et al., 2002). In addition, since the trend of mass customisation and personalisation is evident more and more products are being made through build-to-order (BTO) supply chains (Krajewski et al., 2005). Although CS methods have not been suitably adapted, certain papers mention that – in (Ragsdale & Zobel, 2004) all cutting orders have to be cut in the order of their arrival – which should enable easier mass customisation. Trkman and Gradišar (2005a) also studied the challenges that mass customisation poses to the CS problem.

Finally, the developed methods should be properly included in decision support systems of the organisation and also be simple to use for users lacking detailed operations research knowledge (Čižman & Černetič, 2004) – the methods should include effective support of the user's interaction (Kos & Duhovnik, 2002). Ideally the methods should be integrated in the ERP system of the organisation to enable their routine use (Hoffman, 2000). Only in this way will the relevance of CS optimisation methods increase. Therefore, understanding the cutting process also enables the development of better operations research methods, while the renovation of the CS process can help in their implementation and usage.

The presentation of the limitations of the existing CS optimisation methods serves to highlight the main contribution of our paper. The main contributions presented via the case study in the next section are:

- an analysis of how the optimisation of the CS process in a broader sense can bring the company more benefits than optimisation of the CS problem;
- an proposed approach to the measurement of different kinds of costs of the CS process and the benefits of its renovation; and
- proposed further research topics that arise from the broader treatment of the cutting stock process.

Our approach enables the separation and measurement of different costs (trim loss, cutting machinery costs, labour costs). The last two types of costs can be distributed by activity, group of activities, transaction or department. In addition, process lead times and their variability can also be measured. While our approach was used in a case in the non-ferrous metal and iron industry it can also be applied to other industries where CS or similar problems are involved.

4 Methodology

A case study has been used as a research method to underline the theoretical findings set out in previous sections, i.e. to show how the CS process can be considerably improved with its renovation and how the improvements can be measured.

A case study as a research strategy has a distinct advantage in situations when 'how' or 'why' questions are being asked about a contemporary set of events over which the investigator has little or no control (Yin, 2003). Case studies typically combine data collection methods such as interviews, questionnaires and observations (Eisenhardt, 1989). They are appropriate for capturing the relevant facts with respect to understanding complex decision-making processes (Buxey, 2006). Finally, case-study research is used to tackle areas that are still in the understanding, discovery and description stage (Stuart et al., 2002), which is certainly the case of CS process research.

A flowchart technique was used for business process modelling. It is defined as a formalised but flexible graphic representation of a program logic sequence, work or manufacturing process, organisation chart, or similar formalised structure (Lakin et al., 1996). Flowcharts are built to offer an enhanced comprehension of processes which is a requirement for process improvement such as identifying bottlenecks or inefficiencies (Aguilar-Saven, 2004). Since it is easy to use it is possible to use it in the information gathering phase where the co-operation of the employees is needed. One of its weaknesses is that it can result in large and complicated flow charts (Aguilar-Saven, 2004), which was in our case avoided by simplifying the parts of the process that are not crucial.

The improvement of the process was measured by simulations. Simulations are one of the most often used techniques in operations management both in research and in practical setting (Lane et al, 1993) and can also be used to measure process improvements in either single companies (e. g. Bosilj-Vuksic et al., 2002) or supply chains (e.g. Trkman et al., 2007). Simulations have emerged as an important tool in the process of organisational learning and change-management, focusing on the strategic as well as operational levels of intervention (Fowler, 1998). Simulations support experimentation, allow a deeper understanding of complex process interactions and can enhance co-ordination and communication (Melao & Pidd, 2003). They enable the modelling of process dynamics, a quantitative presentation of re-engineering effects and process visualisation (Bosilj-Vuksic et al., 2002).

In our case, the simulations were used to allow an easier comparison of both states before and after the renovation. In addition, simulations in the AS-IS model enabled the measurement of the whole process in a one-year time period which reduces the effect of coincidental influence on lead times and costs in build-to-order production. Finally the simulations also enable an assessment of possible further improvements and what-if analyses. Required inputs are the flowchart of the process and an estimation of the distribution of the times of all activities. A lognormal distribution was used for sampling the times of activities in production because it is a sufficiently flexible theoretical probability distribution for modelling production times (Graham et al., 2005).

5 Case study: renovation of cutting stock process in a retail company

We studied one of the leading retailers of a wide variety of technical products in south-east Europe where the renovation of the cutting process and the processes connected to it, such as sales, logistics etc. (named marginal processes in the rest of this paper), was made. One of their retail areas is the resale of various metal products which need to be cut by the retailer to meet the customer's demands. Therefore, their production department consists of different types of cutting metallurgy, varying from one- to three-dimensional. Most of the production is build-to-order, which requires them to be flexible and responsive (Gunasekaran & Ngai, 2005).

The main goals of the process renovation were more efficient resource planning, increased process thinking amongst employees and the easier tracking of the materials used in the process. However, the results were poorly measured and the company is unsure whether additional enhancements of the process could be made and how they could be measured.

In order to thoroughly examine the introduced changes a comparison of the previous and current states of the processes was made. Special care was taken in supporting the case study with data.

The following steps of collecting data were taken:

1. Collecting data from the company's internal documentation including cutting renovation project reports, cutting process flow charts and internal information system production data,
2. Validating the data gathered in the first step by consulting process planners in the company,
3. Gathering data from the employees directly involved in the process in order to supplement the existing data.

5.1 The AS-WAS process

The description of the AS-WAS process is as follows: it started with the receipt of wholesale orders in the sales department by a salesperson, while retail orders were received in the purchasing department by a purchaser/planner. If the required product was not in stock and had to be cut the cutting order for production was created and sent to the purchaser/planner who prepared the cutting plan. All orders were printed on paper before being delivered to the planner. Therefore, the planner had to manually re-enter the order in their information system.

The production planning commenced after the planner received the order. The availability of resources (materials in stock, cutting staff, machines) was checked during the planning phase but could not be fully optimised because the information systems were not integrated. The planner only had access to the production plans but not to the ongoing execution of the plans in production. Planning was undertaken separately for each order. After that the documents for each order were prepared. The documents only included the sold materials without the expected trim loss or reusable material. Therefore, the amounts of material in stock always appeared to be higher than the actual situation. This led to different orders using materials from the same batch at the same time and resulted in a delay of about 15% of the orders, which had to be corrected or queued.

After that the logistics department moved the cutting materials for a single order from a warehouse either far away or nearby to the place of cutting in the production department where the order was cut. Finally, the partly used material and product were measured and labelled by the cutter. This was followed by returning the partly used material to the warehouse, disposing of the trim loss and delivering the product to the shipping department. Trim loss was later shipped to a waste management company while partly used material was stored. The AS-WAS process flow is shown in Figure 1.

Before the cutting process renovation the company faced several issues that they believed affected the cutting efficiency. During the initial analysis the following critical problems were identified:

1. Each order was processed separately regardless of other orders which led to inefficient resource planning and, in the employees' opinion, also higher trim loss.
2. Exact data about stocks in the warehouse were unavailable because the production order documents only contained the ordered amounts without reusable materials or trim loss.

The lack of real-time data on stocks led to multiple production orders using the same materials. The orders had to be modified, which caused delays.

3. The production planning information system was separated from the retailer's ERP system; therefore a manual re-entering of data into different information systems was needed.
4. There was no aggregated information on trim loss; it was therefore impossible to track the trim loss and compare these costs to other costs in production.

In addition, the unsuitable information system posed several problems for the marginal processes. The sales department did not have separate data on production and material costs. This led to restrictions when negotiating prices with customers because the sales department was responsible for negotiating the price of cut material.

After the analysis the following goals were set for the process renovation:

1. More efficient resource planning by aggregating production and movement orders to lower material movement costs, trim loss and delays.
2. The easier tracking of the products, reusable material and trim loss in the process and ensuring only the one-off entry of data.

(Figure 1)

5.2 Process renovation

In order to deal with the problems described in the previous section a process renovation was undertaken. It included all departments in the company that are involved in the cutting process.

The most important changes were:

1. Merging wholesale and retail orders in one department.
2. Centralising the planning and moving it closer to the production level.
3. Aggregating the orders on the planning level to improve resource planning.
4. Integrating different information systems within the company which enabled the easy tracking of materials in real-time and ensured that data only had to be entered once. As usual information technology has played a vital role in the success of the overall reengineering initiative. In such a way an integration of functional areas can also be improved (Gunasekaran, Kobu, 2002).

The description of the AS-IS process is as follows: wholesale and retail orders are received and processed in the sales department. If the required product is not in stock and has to be cut, the cutting order for production is created and sent to a production technologist (PT) in the production department. Due to integrated information systems the order only has to be entered by the salesperson in the sales department and everyone else involved in the process can later access and alter the data.

The production planning is now conducted by PT who can use the integrated information system to optimise the selection of the material that is best suited to a certain order considering the quality, size, delivery date etc. While creating the plan PT checks all orders in the queue and tries to merge different orders together. If the time schedule permits PT waits for additional orders. The company's internal rule is that all orders must be cut within five working days. The only exception involves special orders that are too large to be cut in this time period. Therefore, several orders can be issued simultaneously.

This is followed by the internal movement of materials from a warehouse that is either far away or nearby into production. Afterwards the cutting of a joint order is carried out. Finally, the trim loss, partly used material and product are measured and labelled by the cutter. This is followed by returning the partly used material to the warehouse, disposing of the trim loss and delivering the product to the shipping department. The trim loss is later shipped to a waste management company while the partly used material is stored. The AS-IS process flow is shown in Figure 2.

(Figure 2)

During the cutting process renovation the marginal processes were also clearly identified and connected with the cutting process. As seen in Figure 3 the CS process is composed of two separate planning processes, the moving of materials and the cutting itself.

(Figure 3)

Without an identification of the marginal processes the planning information system could not be properly integrated with the retailer's ERP. The most important gain of the integration is optimised resource planning. Using integrated systems simultaneously enables PT to minimise the trim loss and optimise the cutting process based on real-time data on the availability of resources. The analysis of the marginal processes also helped in identifying those departments responsible or eligible for certain data because it showed the interconnection of the processes. In this way the sales process then gained access to data on material and production costs (cost price). This provides better information for the sales department in its negotiations with customers.

The new information system served as an enabler and facilitator of changes. Because of the better and faster information flows the productivity of the existing resources improved. This led to certain parts of the process being under-utilised and needing additional resources. Therefore, additional workers were employed along with investments in new equipment.

6 Analysis of the process renovation benefits

The AS-WAS and AS-IS models were used in simulations which were made with the iGrafx Process. A comparison of the AS-WAS and AS-IS model was made to show the effects of process renovation while the AS-IS simulation alone is used to present an approach to measuring the magnitude of different process costs compared to the trim loss. The data used in simulations was provided by the retailer. In the AS-WAS model data from 2004 (before the process renovation) were used while the AS-IS model includes data from 2006 (after the process renovation). The new employees were employed in logistics and cutting to cope with the new equipment demands and rising quantities. The depreciation period for the equipment is 10 years. The number of employees working in different parts of the process was 41 in 2004 and 56 in 2006. The simulation period was one year for both models. The aggregated results of the simulation are shown in Table 2.

(Table 2)

The indexes in Table 2 show that the growth of the number of processed orders per employee was considerably higher than the increases in the value of equipment and quantity of labour. This implies that the process renovation along with the information system integration supported by modernised cutting and logistics equipment boosted the efficiency of the cutting process.

The comparison of the simulations of both models confirms our previous statement. In Table 3 average service, working and service waiting times are shown together with their respective standard deviations. Service time is the time it takes one transaction to complete the entire process but does not include inactive time[1]. Working time is the time a single transaction spends being processed while waiting time shows how long a transaction waits for available resources. After the process renovation all activities from the purchasing department were moved to the production department therefore the purchasing department is no longer involved in the process. In the AS-IS model the average service time of transactions is nearly halved. Better performance of the logistics department is a major factor in this improvement.

(Table 3)

The cutting process renovation is even more important since companies strive to improve their customer service – two key attributes of which are the duration and reliability of the order-fulfilment time (Denton et al., 2003). As seen in Table 3, the variability of the average service, work and service waiting times significantly decreased in the logistics department while staying the same or slightly changed in other two departments. However the variability in service waiting times in production slightly increased which is a result of slower increase of resources (cutting equipment) compared to the increased amount of processed orders. Nevertheless, this still leads to a smaller overall variability of the CS process which enables a

[1] Inactive time is the time the transaction waits at any part of the process because the process is not being carried out. This happens outside of working hours of the company.

faster and more reliable customer service. The reduction in variability of lead times is crucial for financial performance of companies (Christensen et al., 2007).

The average costs per cutting were also lowered as can be seen in Table 4.

(Table 4)

The approach also enables an estimation of the costs for each part of the process and their comparison with the total trim loss, which can be seen in Table 5. The sum of costs in Table 5 slightly varies from the data provided in Table 4. The reason for this is that some orders were batched at certain points or did not go via the same path through the process. Since the company had no exact data on the trim loss in 2004 we deemed it unnecessary to provide the average trim loss costs for that time period because a comparison with the trim loss per cutting could not be made.

(Table 5)

The estimation of the trim loss was based on internal data provided by the retailer and the results of the simulations. The average value of the trim loss in 2006 was € 90.3. A comparison with the average costs of the process or parts of the process per cutting can be made to see which parts have significant costs that could be improved in order to further decrease the overall costs per cutting.

7 Discussion

The renovation of a CS process leads to significant improvements. Cycle times are shorter and the costs per order are lower. A better and integrated information system enables the measuring of costs by activity, offers better flexibility and ensures reduced variability in the process.

Improvements in the cutting process can lead to significant savings compared to the trim loss per cutting. This mainly depends on the value of the materials used. In our case, the average value of the trim loss per cutting (€ 90.3) is comparable to the cost of certain parts of the process as seen in Table 5 and thus make the process renovation worthwhile. The average costs per cutting nearly halved, from € 99.4 in 2004 to € 53.0 in 2006. Unfortunately, a comparison between the savings due to the process renovation and the trim loss between 2004 and 2006 could not be made because the company was unable to provide data on the trim loss value in 2004.

Therefore, our approach is useful for assessing whether improvements in the CS process compared to the cost of the trim loss are worthwhile. In our case, the cost of labour and equipment in the CS process have the same order of magnitude than the costs of the trim loss and thus a reduction in these costs is clearly important.

Improvements in cutting process also lead to a significant decrease in average process cycle times and their variability. Our case shows that process renovation nearly halved the average CS cycle while variability decreased mainly in the logistics department due to the better information system support and consequently better planning.

The results of the simulation seen in Table 5 also enable an estimation of the costs of the preparation of production and reusability costs. These results are a vital input for some optimisation methods (e.g. Trkman & Gradišar, 2007), which include the reusability of material as an approach to decreasing trim loss costs. The justifiability of such an approach can be studied and the appropriate upper and/or lower bounds for reusable material can also be estimated.

It is also important to note the significance of floor organisation while assessing costs. As seen in our example of two different warehouses the average costs of moving materials from the far away one (€ 10.67) easily exceed the average costs of moving materials from the closer one (€ 2.89). This raises a question regarding the study of the interconnection of cutting and warehousing costs that is listed in the conclusion as an important topic for further research.

It should also be noted that the developed approach can be used with any kind of CS process. In our example it was used for non-ferrous metal and iron industry products.

8 Conclusion & further research

Preparation of the cutting plan is not an isolated activity but instead forms part of a business process within a company. In the paper we proposed a new simulation-based approach to optimisation of the CS process which enables the identification and measurement of different kinds of costs (e.g. equipment, work, trim loss) by department and/or activity. Lead times and their variability can also be estimated.

Therefore, while most papers treat preparation of the CS plan as an individual activity the development of integrated decision-support methods within the CS problem is needed. The paper's main limitation is that the method for preparing the CS plan has not been adapted accordingly. Additional effort is needed to connect process optimisation with the changes and improvements in CS algorithms. Methods in e.g. (Chauhan et al. 2007; Trkman & Gradišar, 2007; Yang et al., 2006) seem to be particularly appropriate for this purpose.

The treating of CS as one of the processes in the company also opens several additional areas for future research such as:

- as shown in our case complete information about the available stock and desired order lengths is often lacking. Therefore, the development of methods for stochastic optimisation amidst uncertain demand and/or inaccurate information about stock lengths is necessary;

- the CS process is not an isolated process in the company; hence the development of methods, the connecting of the optimisation of the CS process with different inventory and ordering models could lead to further decreases in CS process costs;
- consequently the development of a mathematical model that would optimise the combination of cutting, warehousing and purchasing in order to maximise the business benefits of a company or a supply chain is needed. Warehousing costs were namely entirely neglected in our current model. Scheduling and proper production floor organisation are also important topics as illustrated in our example, where the location of the stored material has an important influence on the cutting costs;
- the importance of transforming the CS process in order to facilitate mass customisation has been previously emphasised (Ragsdale & Zobel, 2004; Trkman & Gradišar, 2005a) and the implication of CS process renovation was mentioned (Jiang et al., 2006). But the study of the necessary changes in production and the cutting process along with its costs and benefits is lacking;
- the treating of the CS problem within the supply chain management context has not yet been studied. It was shown that those companies that have redesigned their manufacturing systems introducing pull production, process layout etc. have also increased their integration with their suppliers (Cagliano et al., 2006). The linking of supply chain strategies with CS process reorganisation is another interesting topic, which requires a study of possibilities of application of business process management techniques to supply chain management implementation in multi-organizational environment (Bae, Seo, 2007). The proposed approach can also be used to measure renovation effects in a supply chain context (see e.g. Trkman et al., 2007).

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Figure 1: Model of the AS-WAS process.

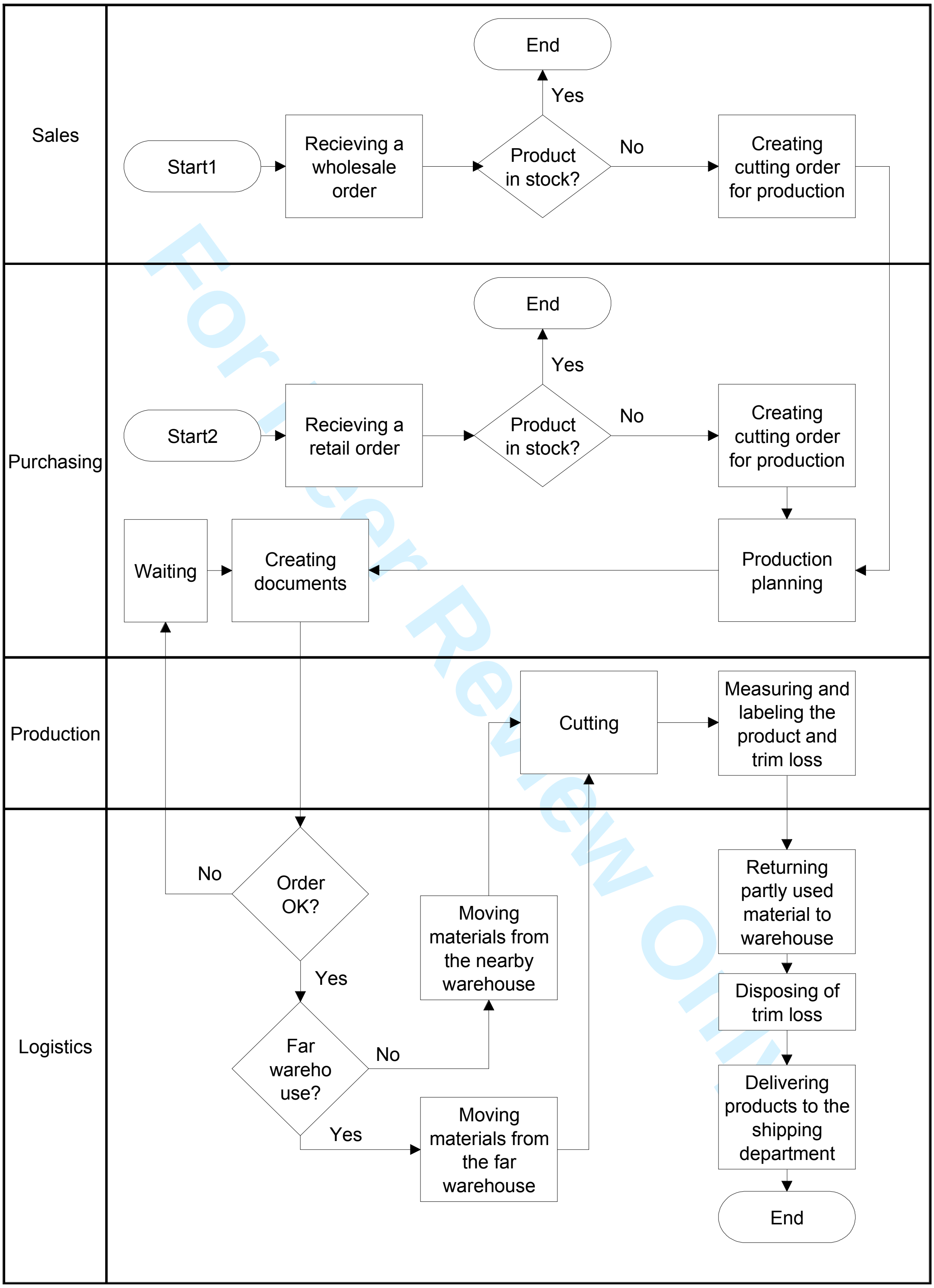

Figure 2: Model of the AS-IS process.

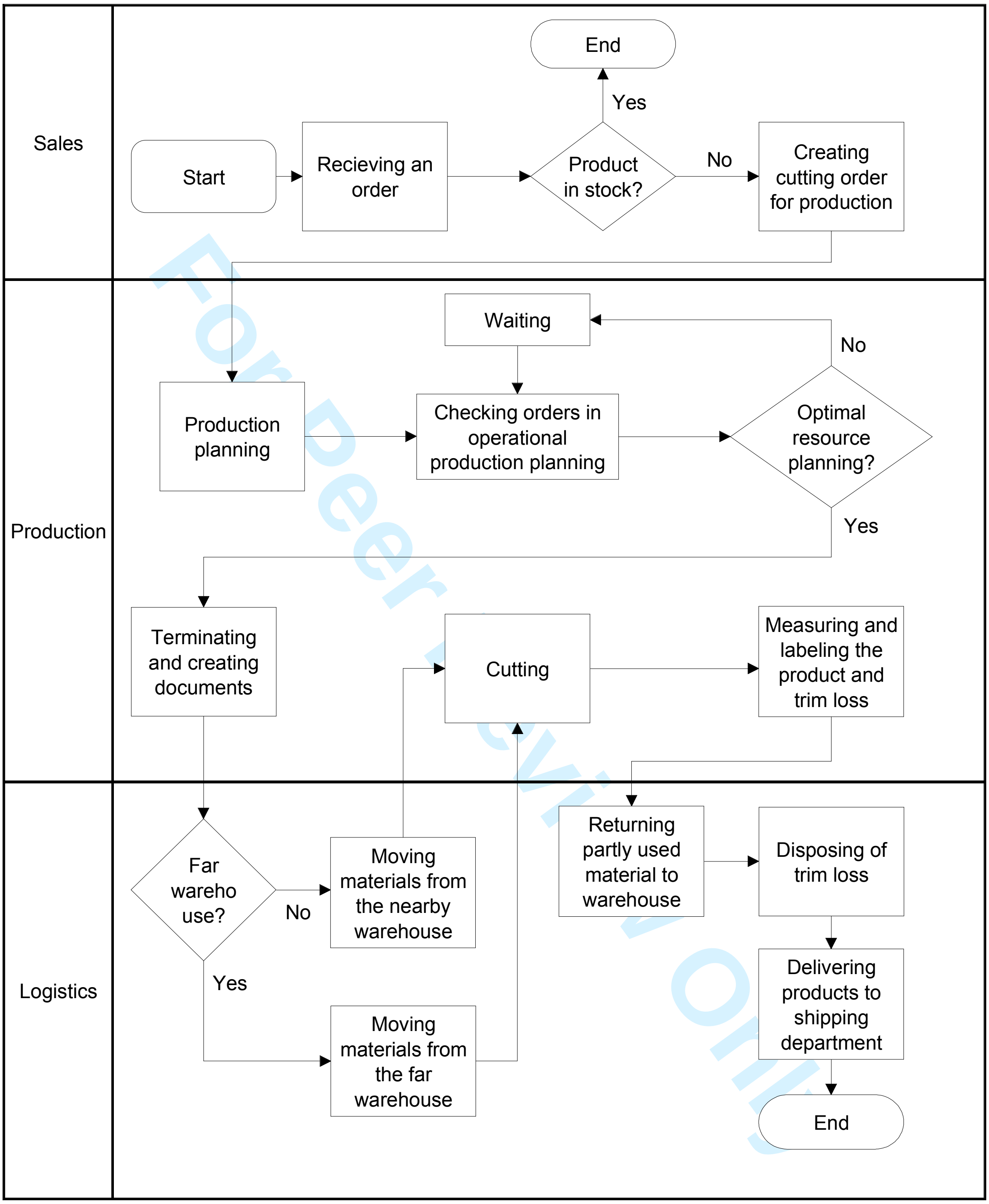

Figure 3: Model of marginal processes for the build-to-order cutting stock process.

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OFFENDING COMMAND: --filter--

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true
222
216
-savelevel-
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