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A Method to Improve Planning of Product Placement on a Printing Sheet

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Abstract
Major manufactures are moving towards a sustainability goal. This paper introduces the results of collaboration with the leading company in the packaging and advertising industry in Germany and Poland. The problem addresses the manufacturing planning problem in terms of minimizing the total cost of production. The challenge was to bring a new production planning method into cardboard manufacturing and paper processing which minimizes waste, improves the return of expenses, and automates daily processes heavily dependent on the production planners' experience. The authors developed a module that minimizes the total cost, which reduces the overproduction and is used by the company's manufacturing planning team. The proposed approach incorporates planning allowances rules to compromise the manufacturing requirements and production cost minimization.

Keywords
Manufacturing operations, production planning, optimization, mathematical programming.

Introduction

Production planners should be mindful of the production environment, the tools required, and environmental practices when producing the product fully in line with customer's requirements. Such tactics help them provide customers with the best available solutions, simultaneously cut costs, and support eco-sustainable processes. Current technical advances make it easier for goods and services to maintain their high quality and be environmentally sustainable.

This research is dedicated to leading in the packaging and advertising media industry company known in Germany and Poland. Among the scope of their expertise is standard packaging for all types of industries and advertising, gift, and decorative materials. Both medium-sized national manufacturing and global brand-name companies from all over Europe are using services provided by them. Among their responsibilities are different services such as process management, packaging, and logistics. Therefore the implementation of new methods which allow increasing speediness and efficiency of their operations is needed.

Among the key strategies of this company is also the direction of "green packaging" which allows achieving high level of production of sustainable and environmentally friendly packaging. Obviously, such a policy helps to protect the environment for future generations.

This company works in a sustainable manner combing economy and ecology into a primary corporate strategy. On the one hand, their offered packaging uses remarkably little material. On the other hand, the goal is to minimize the waste of material and protect the environment for a long time. Such goals are achieved with the help of innovative carton board materials and ecologically environmental packaging solutions. Moreover, the company continuously tries to improve its primary activity process, minimizing the emissions and energy and water wastes.

A modern manufacturing corporation should consider the environmental effects of its operations and manage resources, waste reduction in consistence with the principles of eco-development. Global companies perform special steps to introduce green technology systems because they are cheaper than traditional sources for larger premises.

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Today production planning relies on its know-how and experience to manage day-to-day production. In the best case, it uses prioritization methods focused on analytical criteria. Both approaches prove to be unreliable in terms of time-saving and resource optimization. This scenario highlights the need for an efficient system to support production planning activities.

This paper introduces a novel mathematical formulation of the printing planning problem and gives the opportunities to solve the problem using the commercial solver.

The following sections of the paper are organized as follows. The following chapter presents the literature background. Further, sections with a problem definition and a problem formulation can be found consequently. The next ones describe the authors' computational experiments and present the discussion of the results. The last two chapters conclude the paper and give some directions for future research.

Literature background

Production planning includes all tasks intended to meet the customer's requests, i.e., obtaining component requirements, scheduling production tasks, and supplying the completed product to the customer. It requires resource allocation problems to be solved regularly. In recent years, manufacturing is getting more automated, computerized, and complex.

The purpose of the production planning and control operations is to determine what, how much and where to make, procure and produce so that the business can balance manufacturing output with consumer requirements (Bonney, 2000; Bueno et al., 2020).

To succeed in the modern economy, small and medium-sized companies are now faced with problems that need to be more flexible and agile. This includes a reassessment of the feasibility of current production planning and control processes to create a competitive advantage for the company (Koh and Simpson, 2007).

Effective management by cost savings, quicker operation, and improved flexibility are today's operations modeled together with the continued burden on inventories through just-in-time delivery. All of this makes the management of production processes even more complicated to ensure the supply of the suitable goods, in the right quantities and consistency, and at the right time (Ashayeri and Selen, 2005).

Mathematical programming is widely used in various production planning problems (e.g., Kucukkoc et al., 2016; Li et al., 2017; Bilgen and Çelebi, 2013). Mathematical formulations approaches require many simplifications to model realistic production planning problems. The critical point in mathematical programming models creating is the definition of variables, which results in the efficiency, size, and applicability of the proposed model.

Kucukkoc et al. (2016) proposed a mathematical model for resource usage optimization. Li et al. (2017) presented a problem model intending to minimize the average cost of production per material volume. Their approach and heuristics are proposed to enable to achieve significant cost reduction.

Bilgen and Çelebi (2013) worked on the yogurt production line of the multi-product dairy factories. They developed a mixed-integer linear programming model with the profit maximization function considering various constraints such as pricing, costs, setup, storage, backlogging, overtime, transportation.

Fazel et al. (2020) summarized the advantages and disadvantages of using constraint programming.

Among the constraint programming (CP) advantages are the following:

- CP is dedicated to a more dynamic simulation language, which is more intuitive and similar to natural language.
- CP is descriptive, i.e., after defining the problem, the result could be obtained without focusing on the particular approach applied to solve the problem.
- CP allows for an efficient domain validation algorithm for global limitations.
- CP can be used to model particular "formalized" variable types (e.g., the tasks or interval variables that are suitable for modeling the scheduling and sequence problems).
- CP implements an advanced search technique.
- CP is very efficient on complex scheduling issues (Fazel et al., 2020).

Among the CP disadvantages are the following:

- The utility of constraint programming is always inconsistent, and intuition is always the most critical aspect of determining when and how to apply constraint in CP.
- The search engines available for CP are relatively unsophisticated.
- A lower bound may not be determined by CP (Fazel et al., 2020.

In manufacturing enterprises, short-term and long-term planning is vital to sustaining productivity and service standards. Heuristic, experience-based management can be adequate for small companies; however, the magnitude of the issue rapidly reaches the size that software assistance is required. A range of applications is available on the market that offers a common approach to a problem type, e.g., production plans or equipment assignments. However, such software also follows complex business procedures, which ensure that the company must reorganize itself to obey the processes introduced in the computer program. Another fundamental difficulty is how to cope with application-specific or unique parameters that are extremely expensive or cannot be configured (Frits and Bertok, 2020).

Some authors proposed heuristics (Li et al., 2017; Burger et al., 2015; De Antón et al., 2020; Chergui et al., 2018) and metaheuristics (Alonso-Pecina and Romero, 2018; Elaoud et al., 2007) for solving production planning problem. The usage of data for industrial process intelligence is of growing significance on the road to organizational excellence. In fact, the widespread use of process activity, control computers, and information networks make the current manufacturing process management databases large and massive. Therefore Big Data Analytics is required to be used in manufacturing processes to turn into digital transformation to gain business value. Big Data is described as the ability to manage data with four characteristics: volume (the size or scale of the data), variety (the form, format, heterogeneity, diversity of the data), velocity (the rate or frequency of the data being generated) and veracity (the uncertainty, degree of truthfulness, reliability of the data) (Belhadi et al., 2019).

The manufacturing printing industry has a significant influence on economic and production progress. In order to meet the demands of the modern enterprise, as well as to adapt the business process to the evolving requirements and regulations of this field, more effort should be made to concentrate on new approaches aimed at optimizing the real case production planning issues that occur in the paper printing industry.

Karagul et al. (2018) presented a mixed-integer programming model of the capacitated lot-sizing problem with the defined times and defined carryover. Moreover, they compare four different mixed integer formulations of the lot-sizing problem when production capacity is limited. The practical application of such a problem is print services that offer to print TV billings, health insurance, or other agreement forms with multiple-deadlines, i.e., delivering different numbers of documents on different days for different customers.

Some studies presented the printing problem such as job splitting (Ekici et al., 2010), advertisement printing (Mohan et al., 2007, label printing (Hsieh and You, 2014; Yiu et al., 2007), the napkin printing (Frits and Bertok, 2020), the book cover printing problem (Alonso-Pecina and Romero, 2018; Elaoud et al., 2007; Tuyttens and Vandaele, 2010; Romero and Alonso-Pecina, 2012) and color printing (Burger et al., 2015).

Frits and Bertok (2020) focused on planning and scheduling problems. They presented an optimal production plan for printed napkin manufacturing concerning the optimal selection of the number of orders in the available time frames, consumer priorities, due dates, and the given amounts of raw materials.

The cover printing problem specifically targets the book industry and consists of finding the best possible assignment of book covers on offset printing plates. Such assignment should minimize both the number of used plates and the overall number of paper printed copies and meet the specifications of the different titles of the book in order to minimize the total cost of production. It also specifies the number of sheets to be printed on each plate such that the quantity demand for each book title is met (Elaoud et al., 2007). Alonso-Pecina and Romero (2018) also focused on book cover printing problems aroused in the printing industry with total cost minimization criteria function. They proposed simulated annealing and linear programming techniques as well as hybrid Tabu Search involving ad-hoc procedure. Elaoud et al. (2007) developed two evolutionary algorithms applied to solve the cover printing problem. They combined an adaptive genetic algorithm with a linear programming solver.

Burger et al. (2015) investigated a job scheduling problem that occurs in the packaging industry during overlay color printing. Plastic and foil wrappers and packaging material used with chocolate bars, snack foods, and other products generally require multiple color overlay printing. The printing machines used for this function typically produce a limited number of colors that are concurrently loaded into a magazine. The researchers proposed exact and heuristic solution approaches to this color print scheduling problem.

Sawik et al. (2002) proposed the mixed-integer model for blocking scheduling of printed wiring board assembly of various configurations of surface mount technology lines. The goal was to find an assembly schedule for a different board type to complete the boards within the minimum time interval.

A mathematical formulation of the additive manufacturing (AM) problem could be found in some recent researches (e.g., De Antón et al., 2020; Chergui et al., 2018; Dvorak et al., 2018).

Chergui et al. (2018) modeled a planning problem in which orders produced for different customers are scheduled before the due dates. They also proposed an efficient heuristic solution for this AM-optimized production.

Dvorak et al. (2018) highlighted the AM nesting and scheduling problem in which the orders are printed on different machines while minimizing time concerning deadlines and a set of constraints. Their approach was configured to use two methods: mathematical modeling of nesting parts into builds optimization problem and scheduling the defined builds to machines.

De Antón et al. (2020) proposed a heuristic approach to increase production planning productivity of the 3D printing or manufacturers scheduling the production of several 3D printers in a daily shift to maximize the profit obtained at each 3D printer.

In terms of sustainability, this is important research as the paper industry produces a vast amount of waste paper and waste heat.

Alonso-Pecina and Romero (2018) concentrated on waste paper recovery industrial problems and waste heat to get a cradle-to-cradle zero-discharge production planning technique for the pulp and paper industry. Reuse of waste paper incorporates the paper process from pulp to green product. The next cradle-to-cradle system recycles waste paper for continuously processing it in a cradle-to-cradle discharge production planning system. Their multiobjective framework goals are to maximize waste paper recovery rate, condensate reuse quality, and minimize the total cost of the whole zero discharge manufacture system (Jeng et al., 2019).

Oztemel and Gursev (2020) focused on the optimization models for production planning concerning a circular economy in the following fields: disassembly for recycling, recycling of products and raw materials, by-products and co-production, greenhouse gas emissions producing and energy utilization.

Key results by Oztemel and Gursev (2020) revealed an ever-growing interest in making conventional linear manufacturing systems sustainable in the sense of a circular economy. Throughout the new age of world trade, global warming, and the exhaustion of World's natural resources, the ability to achieve sustainable and competitive advantages means that people must avoid thinking linearly (produce, use and dispose of) and step towards a circular strategy by closing resource loops.

Some researchers reported the aim to minimize waste materials (e.g., Jeng et al., 2019; Tseng et al., 2018; Tseng et al., 2019).

The technique of production of tomorrow is called smart manufacturing. Smart manufacturing is an evolving development method that combines today's and tomorrow's industrial assets with sensors, computing systems, technological developments, monitoring, simulation, data-intensive modeling, and computational engineering. It uses the principles of cyber-physical networks spearheaded by the Internet of Things, cloud computing, predictive engineering, infrastructure computing, artificial intelligence, and computer science. Smart manufacturing has drawn the interest of businesses, government agencies, and academic institutions. When applied, those ideas and innovations will make smart manufacturing the cornerstone of the next industrial revolution (Kusiak, 2018).

Smart manufacturing is the main element of Industry 4.0, production planning and control principle; it should play an important role in the operations of Industry 4.0. Therefore the continual adaptation of business and manufacturing operations, strategic environments, comprehensive customer requirements should be performed. Industry 4.0 technologies are used to maintain production planning activities (Bueno et al., 2020).

The industry directs its efforts on the transition of industrial machine suits to intelligent products and future buyers of this development. Industry 4.0 presents a methodology for producing the transition from powerful machine traditional manufacturing to digital manufacturing. Industry 4.0 and associated development along this line would have an important influence on social life. This will inevitably drive the production companies to enhance their manufacturing suits to satisfy consumer needs and retain a competitive edge (Oztemel and Gursev, 2020).

Some recent researches highlighted the usage of Industry 4.0 (Bueno et al., 2020; Oztemel and Gursev, 2020; Tsai, 2018).

Tsai (2018) used the combination of mathematical programming and Industry 4.0 in the textile industry while modeling green production planning with the profit maximization criteria function. With the help of mathematical programming, they found the optimal product mix under many production constraints. In terms of green production, this allows the appropriate recycling waste to reduce carbon emissions, save spent cost and energy, and reduce the material quantity. The proposed approach helps textile companies ensure the best profitability and control the influence of their production processes on the environment (Tsai, 2018).

Recent achievements in information and communications technology that combine Industry 4.0 allow managing the lifecycle of products on all stages (design, producing, distribution, consumption, recycling), enabling planning, data-driven learning from various data sources, and minimizing waste (Oluyisola et al., 2020).

Problem definition

This research is dedicated to reducing material loss which involves improvement in materials usage, printing less extra reserve elements, and as a result, reducing the total production cost. The printing and packaging company makes an effort to improve the printed element's cost by utilizing various planners' various methods, raising quality improvement. Most of the work is done manually, and the adjusted data parameters strongly depend on the planner's experience. The manufacturing company aims to achieve a highly efficient package production process to prevent much cost generation by appropriate initial parameters selection.

The printing and packaging company needs to print lots of various types of packages for many customers using several tools (sheets that can be mounted on a printing machine) that vary in each order pack. Each instrument used in one order pack has the same number of slots (each slot can be used for any product) per sheet and the number of repetitions per sheet. The cost of the sheet is fixed. If the sheet is used, it must print the package type using the number of repetitions per sheet for this machine, i.e., this number can't be reduced in case of minor orders. This leads to the situation in which the industrial company produces enormous extra products. Realizing the need for action, leading businesses are introducing programs to reduce wastes emerging after processing their orders. Considering current trends, total costs from production and overproduction need to be decreased. Therefore in some cases, it is better not to use the additional sheet at all and try to process more orders with fewer slots but on an existing sheet. It also opens the chance to break the order and execute it on several sheets. All sheets are available for printing each order. The objective is to minimize the total cost of production.

There is a number of orders R ($i = 1, \ldots, R$) which must be printed maximum on S ($j = 1, \ldots, S$) sheets. It is possible not to use all available sheets for production processing. Each sheet has a defined number of slots per sheet k and a specified price of its preparation p. The industrial company sets the number of products in the order n_i but it must print more pieces because in case of color printing, the first prints usually are miscalibrated, deformed, or without using the appropriate settings for each color. Therefore they must print at least some number of papers, adding minimum planned allowance per order m to the defined number of products in the order n_i or to print f percents more than the main number of products which is determined by the allowance coefficient f. The overproduction cost per product is known and is measured by h.

To solve the problem, there is the need to define the number of repetitions per sheet x_j and the number of slots for each product order in sheet y_{ij} so that the total cost of the production (including the main printing costs and the cost of overproduction) is minimized. Additionally, the company needs to define the total overproduction A (number of elements), the total cost of overproduction B, the total cost of sheets C, and the total number of sheets D used in production because it allows not using all the available sheets to print the order.

Main variables and parameters:

R – number of orders,
i – order index, $i = 1, \ldots, R$
S – number of sheets,
j – sheet index, $j = 1, \ldots, S$,
k – number of slots per sheet,
p – price of using 1 sheet,
m – minimum planned allowance per order,
f – allowance coefficient,
h – overproduction cost per product,
n_i – number of slots for i-th order.

Additional Variables:

q_i – required production batch for the order, $q_i = \max(n_i f, n_i + m)$.

Decision variables

x_j – number of repetitions per sheet,
y_{ij} – number of slots for product order in the sheet.

Decision expressions:

A – total overproduction

$$A = \sum_{i=1}^{R} \sum_{j=1}^{S} x_j y_{ij} - \sum_{i=1}^{R} q_i\,. \tag{1}$$

B – total cost of overproduction

$$B = m \left(\sum_{i=1}^{R} \sum_{j=1}^{S} x_j y_{ij} - \sum_{i=1}^{R} q_i \right). \tag{2}$$

C – total cost of sheets

$$C = p \sum_{j=1}^{S} \min(x_j, 1). \tag{3}$$

D – total number of sheets used in production

$$D = \sum_{j=1}^{S} \min(x_i, 1). \tag{4}$$

Problem formulation

The model can then be formulated as follows:

$$\text{minimize}(B+C) \Rightarrow$$
$$\Rightarrow \text{minimize}\left(m\left(\sum_{i=1}^{R}\sum_{j=1}^{S} x_j y_{ij} - \sum_{i=1}^{R} q_i\right) + p\sum_{j=1}^{S}\min(x_j,1)\right) \tag{5}$$

subject to:

$$\forall(i)\left[\sum_{j=1}^{S} x_j y_{ij} \geq q_i\right], \tag{6}$$

the order may be divided to be printed on several printers.

$$\forall(j)\left[\sum_{i=1}^{R} y_{ij} = k\right], \tag{7}$$

all slots of the printer must be used.

$$\forall(j)\left[x_j \geq 0\right], \tag{8}$$

the number of repetitions per sheet must be a positive integer.

Computational experiment

The quality of the solution found by the proposed constrained programming model has been estimated during the computational experiment. The experimental data has been received from the cardboard manufacturing company. There were 20 sets of real-world data. They are concerned about production plans for the first two weeks of January 2021. For each data set, the company provided the appropriate production plans, prepared in a standard way by an in-house employee responsible for production planning. Half of the datasets were prepared for printing on machines with 24 slots per sheet, and the other half for machines with 40 slots per sheet.

The optimization was implemented on the commercial solver platform. CPLEX was selected because of the fact that it provides an easy-to-use optimization tool that could be applied in the industry. The computational experiments were performed in IBM ILOG CPLEX Optimization Studio, version 20.1.0.

In the solver usage scenario adopted for the research, it was assumed that the company doesn't have a dedicated computing server. All calculations would have to be performed on the computer used in the employee's daily work responsible for production planning. For this reason, all research solver computations were made with two physical processor cores with a clock frequency of 3000 MHz. The computer was equipped with DDR4 memory with a capacity of 16 GB, and the permanent data was saved on an SSD disk.

The solution of the addressed package printing problem was found by the CPLEX solver and was compared to the solution found manually by production planners. CPLEX solved the task within the following time intervals: 5 minutes, 20 minutes, 60 minutes. The experiments demonstrate that the quality of the solution strictly depends on the predefined solution time. On the other hand, quick access to the solution is also an essential factor in determining usability. Often, the answer to the customer's inquiry must be granted the same day on which the task is received. In such a situation, the computation cannot be queued, e.g., as part of calculations during the night shift. Statistically, about one employee working hour is needed for the manual preparation of allocation of a single production plan in the company. About 50 different production plans have to be prepared each month.

Results discussion

Table 1 presents the total production cost found by CPLEX in comparison to the manual planning. It is assumed that CPLEX was better, so the total cost percentage was calculated according to the formula:

$$(\text{manual-solver})/\text{manual} \cdot 100\%\,.$$

It could be observed that almost in most cases, CPLEX performed production planning on a significantly lower total cost. Better values were received at 1-hour time limit. Unfortunately, for the 5-minute time limit, CPLEX was better only in 7 cases from 20 ones. For 1 hour, the average total cost percentage was better than manual solution 17.26%, with their minimal and maximal values 0.20% and 49.46% consequently. 60 minutes test gave a better solution than the manual one in all cases.

As it was described earlier, the goal was to minimize the total cost of production, but the company also needed to calculate the number of overproduced items. So Table 2 shows the total overproduction found by CPLEX in comparison to the manual plan-

Table 1
Total production cost found by CPLEX compared to manual planning

	Data set id	5 min	20 min	60 min
	1	−5.62%	19.02%	20.21%
	2	−13.49%	−10.07%	0.20%
	3	−41.81%	−22.68%	2.76%
	4	−6.05%	−6.05%	8.05%
	5	−2.51%	2.50%	6.30%
	6	3.52%	10.04%	10.04%
	7	7.12%	7.60%	9.22%
	8	11.59%	18.87%	23.59%
	9	24.75%	28.61%	36.77%
	10	−3.68%	−2.64%	4.14%
	11	23.16%	47.81%	49.46%
	12	20.18%	22.76%	23.76%
	13	−68.18%	12.23%	24.79%
	14	−45.20%	−9.49%	8.61%
	15	−13.47%	5.89%	21.62%
	16	−182.53%	1.85%	4.94%
	17	−65.05%	19.99%	19.99%
	18	15.80%	16.80%	20.57%
	19	−24.54%	9.31%	10.53%
	20	−13.47%	−4.74%	39.58%
Min		−182.53%	−22.68%	0.20%
Avg		−18.97%	8.38%	17.26%
Max		24.75%	47.81%	49.46%

Table 2
Total overproduction found by CPLEX compared to manual planning

	Data set id	5 min	20 min	60 min
	1	35.41%	85.27%	86.97%
	2	7.44%	84.77%	70.71%
	3	90.19%	88.85%	54.81%
	4	24.56%	24.56%	54.49%
	5	82.40%	49.93%	58.75%
	6	54.50%	67.22%	67.22%
	7	82.78%	83.89%	87.66%
	8	42.63%	69.42%	86.78%
	9	74.75%	80.15%	91.58%
	10	78.30%	80.20%	92.77%
	11	63.66%	92.79%	94.73%
	12	87.13%	90.73%	92.12%
	13	−69.10%	59.89%	59.89%
	14	60.97%	90.72%	74.69%
	15	75.93%	85.73%	90.76%
	16	−200.04%	61.82%	66.01%
	17	−35.97%	85.30%	85.30%
	18	82.42%	83.99%	89.93%
	19	3.91%	14.06%	92.36%
	20	75.35%	88.24%	82.24%
Min		−200.04%	14.06%	54.49%
Avg		35.86%	73.38%	78.99%
Max		90.19%	92.79%	94.73%

ning. It is assumed that CPLEX was better, so the overproducing percentage was calculated on the same basis as the total cost. Values below 0 mean that the manual solution was better.

It could be observed that almost in all cases (except 3 cases for 5 minutes), CPLEX produced significantly fewer items. The best results were achieved on the 1-hour time limit. In this case, the CPLEX model found a better solution comparing to the manual one, on average 78.99%, i.e., it produced fewer over product items. This value varies from 54.49% up to 94.73%.

Due to the convenience and simplicity of manual planning and the limitation of machine retooling time, in manual production planning practice, there is the goal to use as few sheets as possible. Table 3 shows that the solver almost in all cases used more sheets in the proposed production plan. The factor that increases the justification of using a larger number of sheets is not the total production volume but the degree of diversification of the size of orders within the given set.

As long-term environmental issues grow, manufacturing corporations are under rising economic pressure to tackle the problem of waste production. Table 2 demonstrates that recognizing the need for action; printing package company should implement initiatives to reduce wastes while overproduction printing. An environmentally friendly industry is developing ways to minimize harm to the environment caused by leftovers.

Table 3
Number of sheets used in the production plan

Data set id	Total number of products	Number of orders	Slots per sheet	Manual planned sheets number	Solver planned sheets number
1	339000	62	24	3	7
2	313000	43	24	3	5
3	215000	40	24	3	4
4	232000	45	24	3	4
5	166000	41	24	2	4
6	176000	32	24	2	3
7	199000	20	24	2	3
8	65000	20	24	2	2
9	208000	42	24	2	4
10	153000	37	24	2	4
11	988200	52	40	2	6
12	577800	40	40	2	5
13	689400	53	40	3	4
14	786600	40	40	2	5
15	743400	50	40	2	6
16	1107000	72	40	3	8
17	907200	58	40	3	7
18	459000	34	40	2	4
19	514800	37	40	2	7
20	558000	37	40	2	3

Conclusions

The challenges of the modern world are getting more complicated. In today's competitive market, large manufacturers are looking for sustainable solutions and services, adopting green policies in their daily operational processes. Therefore in a highly competitive production environment, there is the increasing popularity of expert cost-effective and eco-conscious solutions. Businesses working together will help solve the problems that threaten society and create a better base for the economy and the manufacturing future.

The authors developed a module that helps find a balance between optimizing the production process and minimizing wastes which could be applied to the daily business at the paper processing and package manufacturing company. The authors proposed a mathematical programming model with the help of which the package printing manufacture could minimize the production cost and overproduction cost. The proposed approach has the opportunity to be implemented as a new solution technique for small business manufacturing companies that enter a market segment, and it also could modernize the business of market leaders. The authors showed that some of the differences in the performance of the proposed method depend on the predefined solution time.

Although most clients see only the ending product, the production phase is a vital aspect of achieving green strategies from A to Z. Therefore, manufacturers should do everything in their power to make the most of green policies in production and sustainable tools. The optimal utilization of available resources is a core component of green production. The designed module is a way for the package manufacturing company to be more efficient, reduce expenses from waste operations, and improve the company financials.

The commercial solver software used in the research is distributed in a subscription model. From an economic point of view, the monthly cost of using such a solver is a small fraction of the total savings that will come from implementing more cost-effective production plans. The cost of electricity consumed during calculations is negligible. What's more, the person responsible for production planning will be equipped with a digital tool that, on the one hand, will significantly reduce manual work, and on the other, significantly reduce the possibility of mistake.

Future research

Production planning optimization can be studied in different ways. The approach presented in this paper allows the manufactures to reduce wastes by printing extra elements, which results in lower total production cost. Once the conclusions have been outlined, authors focus on the future research lines that can improve the actual results in different ways:

- improvement of the mathematical programming model and initial processing of given data sets;
- increasing of the computing power to the level that guarantees the maximum reduction of production costs with the minimum cost of calculations.

In the course of the research, it was noticed that putting individual orders into different sheets can, in some cases, significantly reduce the amount of excess production while using fewer sheets. However, this approach to planning forces a significant change in the organization of the shop floor and the complexity of logistics activities in the enterprise. Due to the complexity of this issue, it will be considered in separate studies.

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