Management Systems in Production Engineering

2015, No 1 (17), pp 22-27

DOI 10.12914/MSPE-04-01-2015

CALCULATION OF THE DEADLINES FOR NESTING WITH THE POSSIBILITY OF COMBINING ORDERS

Andrzej JARDZIOCH, Jędrzej JASKOWSKI
West Pomeranian University of Technology, Szczecin

Abstract:
This paper describes the problems associated with determining deadlines for handling production orders during the orders combination process in order to optimize nesting. The analyzed problems relate to an automated nesting system in which production orders come in via the Internet and are processed automatically, and with minimum operator intervention. The article describes the issues of cutting optimization in the manufacturing system based on a water cutter. The optimization process is closely associated with the generation of production schedules for current orders base. Particular attention is focused on the analysis of problems arising from the omission of the human role in the processing of orders, scheduling and decision-making processes.

Key words: *nesting, simulation model, deadlines*

INTRODUCTION

The issue of production scheduling in automatic manufacturing systems for nesting has been raised in a number of scientific publications. This paper discusses the problem of scheduling small batch production using algorithms to optimize the cutting of sheet metal. Subsequent chapters present the problem occurring in the metal cutting process; the problem of ambiguous determination of scrap, the description of the automated manufacturing system implementing the nesting and the algorithm for the operation of the system. The problems of scheduling processing operations occurring in such systems have also been described in detail.

THE PROBLEM OPTIMIZATION OF CUTTING MATERIAL

One frequently studied problems of cutting is an issue that can be described as rod cutting. It is an issue for one-dimensional elements. It can be encountered when there is a number of items of specific lengths are set one after the other. The material to be used for the execution of the order is in the form of rods, and has a predetermined length. The task to optimize involves such arrangement of the cut elements as to reduce the number of the rods used to a minimum. This problem is analogous to the allocation of memory cells. The issue has been widely described in items [2, 3, 5, 10].

Another issue, raised equally often, is the case of cutting a roll of material. It can be specified in the following manner. A material is given with the dimensions (X,Y), wherein the X dimension shall refer simultaneously to the length of the entire roll of the material and the dimensions of the table where cutting will be carried out. In the literature you can encounter 2 ways of describing the shape of the cut pieces. The first way is to inscribe the cut shape into a regular shape – rectangle, square. The second method applies complex geometric calculations. The criterion here is the maximum utilization of the material, i.e. the largest possible number of elements cut out [1, 4, 6, 7, 8, 11]. Depending on the particular company's way of working, there are also several ways of grouping the cuttings in batches.

A derivative of the coil cutting issue is the sheet cutting issue. Hard materials can be made only in the form of sheets with dimensions adapted to the constraints posed by the modern means of transport. When it comes to the sheets, they are transported on pallets, so the dimensions of the material depend on the size of the pallet, usually having a width of 1000, 1250 or 1500 mm and a length of 700 mm to 12,000 mm. The most common standard sheet size is 1000x2000 mm, 1250x2500 mm, and 1500x3000 mm. The dimensions of the sheets of glass and stone are similar. Plastic panels are manufactured in standard sizes but smaller sheets can be ordered. The problem of optimizing the cutting of sheets is similar to coil cutting. In the former case, the table on which you are cutting determined the limits for dimensions. In the case of sheet cutting, the sheet's dimensions are what determines the dimensions of the working surface.

A number of typical cutting technologies are currently in use. One can mention acetylene torches, plasma cutters, laser cutters, cutting plotters, milling plotters, and water cutters. Each of these technologies has its own unique advantages and disadvantages. The choice of technology depends on the type of workpiece. Different cutting technologies also require different ways of fixing the workpiece sheet and the punched element. Depending on the cutting technique, different work tables are available, the construction of which may limit the ability to cut out some shapes. In the nesting process, it often becomes necessary to provide "bridges" connecting the cuts. The function of "bridges" does not allow for separation of the cut pieces and prevents them from shifting during the process. In the next stages of the production process, the "bridges" must be manually removed. This results in additional costs, although this problem is closely related to the machine's technology of operation and there is no clearly defined way of solving it.

THE ISSUE OF MATERIAL EFFICIENCY

In scientific studies, one may come across the approach that the leftovers after the cutting process are conceptually treated as waste. However, there are clear definitions that allow deciding whether the part of sheet metal remaining after the cut is just a waste or can be used to cut smaller pieces. This problem is particularly important nowadays, when one of the most important indicators describing the operation of a company is the efficient use of environmental resources, and acting in accordance with the paradigm of sustainable development. In this case, one should make an effort and think about how to use the material, which has so far been treated as waste.

In the plants involved in the cutting of sheets, there are two types of waste. The first type is the waste that can be called a complete waste. This type of waste is only suitable for recycling. The second type of waste is the so-called "technology waste" that can be used in the future for cutting elements of small dimensions or specific shapes. Determining whether the material remaining after cutting is suitable for further cutting is still a problem that is difficult to clarify unambiguously. To determine whether the residue after cutting is still suitable for use, one must take into account several factors, such as: the smallest shape possible to cut, the smallest size of the material possible to fix, the transport capacity, the manner of storage and customer preferences. Each of these factors limits the way of defining the material. Introducing simplifications in the form of surface material record is not applicable in this case, and can only be used as information for statistical purposes, as it may happen by chance that the remaining material occupies a large total area, but its shape makes it impossible to store, transport or no feasible shape would fit it. One of the ways to increase the reusability of the material is such deployment of the cut pieces, so as to give the element formed after cutting a shape as close to a rectangle as possible. In this way, waste formed in the shape of a rectangle can be successfully treated as full sheet, although of smaller size.

AUTOMATED SHEET CUTTING ON THE EXAMPLE OF E-PRODUCTION

The processes occurring in the nesting process will be presented on the example of e-Production [9]. The system works fully automatically and autonomously, and all existing technological operations take place without human intervention. To reach the largest number of customers, customer contact takes place by remote communication via Internet connectivity [9, 12]. A specially designed website with relevant decision-making algorithms allows placing orders in the system. Other order processing algorithms then determine the production capacity and estimate the due date. The order then goes to the production on a robotic station, and finally the ready pieces are packed and shipped to the customer.

Such an approach to the production process is associated with a lot of issues that usually lie within the responsibility of the human operator. Estimating the date of execution of the order is an issue that is difficult to define. From the customer's point of view, the buffer stock of time used in traditional plants should be as small as possible. On the other hand, determining the deadline for the completion of processing affects the sheet's transport time, cutting time, control measurements and the possibility to combine orders and use the material.

The issue of sheet cutting optimization, mentioned in the previous chapters, and the strictly related problem of setting a deadline of an order can be defined as NP-hard (nondeterministic polynomial time Algorithm) [9]. This means that the time required to find the optimum solution grows exponentially with the complexity of the problem. This article will describe in detail the issue of designating the date of completion of a single order with regard to procedures for connecting it to other orders in order to minimize the technological waste produced during production.

THE IMPACT OF SCHEDULING ALGORITHMS ON THE DEADLINE FOR THE COMPLETION OF ORDERS

Scientific publications related to the problem of cutting treat the issue of cutting optimization as a problem only involving the material itself. They merely find such an arrangement of pieces on the cut sheet so as to leave as little waste as possible. In this article, we extended the problem of cutting optimization with an issue associated with meeting the deadlines of completion. This issue is of particular importance for the production of small batches and individual pieces, when in order to carry out orders, the sheet is often used incompletely and at the same time there is a need to combine different orders. When the plant takes orders from private customers, it often has orders to make a few pieces of the product, which can occupy a small area of the material. To reduce the resulting waste, one can combine orders from several clients. Fig. 1 shows a scheme implemented by the operator to combine orders.

Fig. 1 shows a schematic of a process of "manual" combining of orders. It can be described as follows: the operator gets a set of orders to be executed. Each order has a described shape, material type and the number of pieces to be made. Working under the FIFO principle, the operator enters the subsequent order into the system and checks how the nesting looks. As soon as the sheet is exceeded, the last order entered is removed. The previously entered orders can be called a cut package that will be made of a single sheet.

This way of working is often observed in small companies that do not have advanced software. Since many activities are dependent on the operator, determining time limits for the performance of contracts takes place on the basis of estimating the time of their execution, and is highly biased.

In the case of the considered automated manufacturing system, a module for combining production orders is equipped with an algorithm that allows selecting orders, the combination of which will give the best possible use of material. To ensure the best possible use for the material, one should consider all the orders contained in the database. The combining algorithm must then search all possible combinations of orders. The number of connection possibilities is a combination without repetition.

This means that with the increasing number of orders, the number of solutions is (Table 1):

- for 1 order, the solution is: 1,
- for 2 orders, the new possible combinations are: 2 and 12,
- for 3 orders, the new possible combinations are: 3, 13, 23, 123,
- for 4 orders, the new possible combinations are: 4, 14, 24, 34, 124, 134, 234, 1234.

It can be seen that the number of possible combinations of orders increases in accordance with the formula (1) wherein:

$$S = \sum_{a=1}^{n} 2^{a-1} \tag{1}$$

S – number of combinations of orders,
n – number of orders in the database,
a – order number.

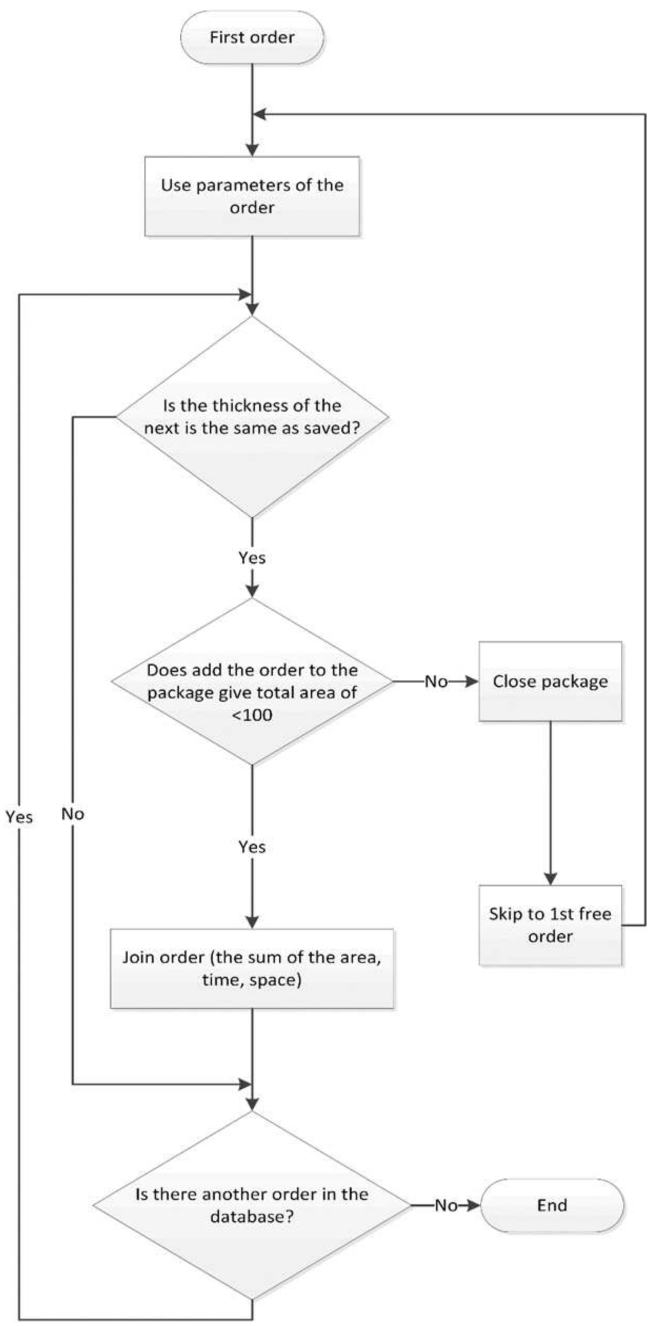

Fig. 1 Scheme of combining orders

Table 1
Possibilities of combining orders

Number of orders	Number of solutions
1	1
2	1+2=3
3	1+2+4=7
4	1+2+4+8=15
…	…

This means that for 10 orders we will receive 1023 options. For a database consisting of 50 orders their possible connections reach the number 112,589,990,684,262.

With so many possible combinations, selecting the best combination of orders is not easy. The basic parameter on which it is possible to assess the quality of the analyzed combination of orders, is to define the deadlines of the orders included in this combination and compare these deadlines with those scheduled. Due to the complicated nature of the relationship related to the performance of the manufacturing process, determining deadlines for production orders included in the analyzed connection is possible only after the simulation study of the schedule. In addition, for each set of aggregated orders inquired, it is necessary to carry out the procedure to optimize the arrangement of cut orders in order to minimize the surface of the used metal or to minimize waste. This means that the manufacturing system operating in accordance with the methodology of e-Production should do the following:

- determine the possibilities of combining orders,
- perform optimization of cutting with regard to the surface of the sheet used,
- carry out a simulation process for manufacturing the analyzed combination of orders to determine the deadlines for individual orders included in the analyzed combination,
- compare the deadlines for the completion of orders with the planned completion dates of orders,
- choose the best combinations of orders (e.g. ones that do not cause delays or cause minimum delay).

One may ask whether it is better to choose a combination of orders that gives more waste but allows for the execution of orders at scheduled deadlines, or to choose a combination that uses material better but generates delay. This is a question that has no definite answer. A simplification with regard to the computation time and the time needed for the simulations is the approach that involves not using the entire database of orders, but only a portion thereof. Dividing the database and taking e.g. only 10 orders for analysis means that the test gets 1,023 possible combinations at a time.

In the case of the collection of partially used sheet metal in the warehouse, the issue of combining orders becomes even more complicated. Instead of a uniform shape of the sheet metal used in the nesting process, partially used sheets of different shapes will appear. The very determination of whether a single shape resulting from the analyzed order is possible to cut with a partially used sheet is a difficult problem. When combining orders, the system may consider partly used sheets of different shapes. This approach yields an even greater number of possible solutions and requires a computer system storing the database of the shapes of partially used sheet metal and identifying the location of these sheets in stock.

Table 2
A set of orders executed in an automated production system

A					B				
Order number	**Thickness**	**Number of pieces**	**Cutting time**	**Percentage of the sheet**	**Order number**	**Thickness**	**Number of pieces**	**Cutting time**	**Percentage of the sheet**
	[mm]	[pieces]	[s]	[%]		[mm]	[pieces]	[s]	[%]
1	2	10	300	3	**Thickness 2 [mm]**				
2	3	10	900	9	1	2	10	300	3
3	4	33	600	6	8	2	5	300	3
4	3	28	2220	22	9	2	2	120	1
5	5	100	1500	15	10	2	75	900	9
6	4	40	1020	10	15	2	28	1680	17
7	4	10	1500	15	20	2	11	1980	20
8	2	5	300	3	21	2	13	4278	43
9	2	2	120	1	**Percentage of the sheet, total: 96%**				
10	2	75	900	9	**Thickness 3 [mm]**				
11	5	66	1800	18	2	3	10	900	9
12	5	10	3000	30	4	3	28	2220	22
13	3	10	300	3	13	3	10	300	3
14	3	17	1020	10	14	3	17	1020	10
15	2	28	1680	17	16	3	56	3600	36
16	3	56	3600	36	**Percentage of the sheet, total: 80%**				
17	5	15	1800	18	**Thickness 4 [mm]**				
18	4	40	2400	24	3	4	33	600	6
19	4	32	3000	30	6	4	40	1020	10
20	2	11	1980	20	7	4	10	1500	15
21	2	13	4278	43	18	4	40	2400	24
22	4	28	152	2	19	4	32	3000	30
23	2	48	999	10	22	4	28	152	2
24	2	95	2470	25	**Percentage of the sheet, total: 87%**				
25	2	35	838	8	**Thickness 5 [mm]**				
26	4	28	152	2	5	5	100	1500	15
27	3	99	8920	89	11	5	66	1800	18
28	4	22	5307	53	12	5	10	3000	30
29	3	84	2050	21	17	5	15	1800	18
30	3	2	5712	57	**Percentage of the sheet, total: 81%**				
31	5	58	3035	30					
32	5	12	7574	76					
33	3	66	3600	36					
34	3	51	8485	85					
35	2	56	9010	90					
36	3	37	3971	40					
37	3	42	2524	25					
38	3	12	6090	61					
39	3	80	18000	180					
40	3	19	1379	14					
41	2	60	6183	62					
42	3	4	8284	83					
43	2	9	2210	22					
44	2	60	8100	81					
45	2	2	5400	54					
46	2	35	85	1					
47	2	76	9592	96					
48	2	80	9500	95					
49	2	90	3600	36					
50	2	34	2280	23					

EXAMPLE OF MANUFACTURE ORDER SCHEDULING INCLUDING MAXIMIZED USE OF METAL SHEETS

The study included carrying out an example of scheduling production orders with respect to their combinations and maximizing the use of sheet metal. To carry out the tests, a simulation model has been developed for an automated manufacturing system and simulation studies were conducted. It was assumed that all transport operations are automated. An initial set of 50 orders was randomly generated as presented in Table 2 A.

For the assumed set of 50 orders, the procedure of manually grouping orders was performed seeking to maximize the use of sheet metal. Manual grouping took about 30 minutes. 4 order packets were obtained, depending on the thickness of the material. This way, the orders 1-22 were collected as shown in Table 2 B. For 2mm the combination includes orders 1,8,9,10,15,20,21 giving a total of 96% material usage. For 3mm the combination includes orders 2, 4, 13, 1, 16 giving a total of 80% material usage. For 4mm the combination includes orders 3,6,7,18,19,22 giving a total of 87% material usage. For 5mm the combination includes orders 5, 11, 12, 17 giving a total of 81% material usage. For the purposes of simulation it was assumed that the machines start work at 8:00 am.

The obtained deadlines for the manufacture are shown in Table 3.

Table 1
End times of production

Order number	End time	Order number	End time
1	11:30:26	12	21:54:30
2	14:23:56	13	14:23:56
3	18:10:20	14	14:23:56
4	14:23:56	15	13:30:26
5	21:54:30	16	14:23:56
6	18:10:20	17	21:54:30
7	18:10:20	18	18:10:20
8	11:30:26	19	18:10:20
9	11:30:26	20	11:30:26
10	11:30:26	21	11:30:26
11	21:54:30	22	18:10:20

The study allowed us to draw some interesting conclusions. As can be seen, the proposed combination of orders results in that the orders are not executed in the order of their registration in the system, but depending on the parameters related to the required sheet thickness and shape. For example, order No. 3 will be performed only after 6 pm, and order number 5 almost at 10 pm. It should be noted that determining the end time of execution is possible only when the orders have been combined in sets and tested by simulation. Only on this basis one can inform the customer when the order will be completed.

It is possible, however, to group orders in another way. By searching the entire database of orders, one can select a different set of orders executed together using sheet metal with a thickness of 2 mm. These could be the orders number: 9, 10, 15, 20, 21, 23. This combination results in a very good (near 100%) utilization of sheet metal with a thickness of 2 mm. However, adopting such a combination will result in that the orders No. 1 and No. 3 are not made in the first place and their dates of completion will delay even more.

SUMMARY

The joint consideration of the problem of combining cutting production orders in order to minimize the waste, and the problem of scheduling orders to ensure timely completion is a new issue and unprecedented in the literature. Although said issue was described on the example of a single-unit system, its solution is related to the construction of complex optimization models of NP hard complexity. Furthermore, in the case of building a fully automated system, there are many decision problems which, in traditional systems, are solved by skilled personnel on the basis of unclearly defined heuristic knowledge. Using algorithms based on artificial intelligence is proposed to solve these problems. A very useful tool in determining the production turnaround proved to be an adequately prepared simulation model. Through simulation research, it was possible to recreate the production process, together with a quick determination of the time limits for the completion of production orders, an analysis of the results and making adjustments accordingly. Each change in the initial scheduling of production orders affects the sets of orders and requires repeating the simulation process. As a result of the implemented studies, the quantitative effect of combining production orders on their completion deadlines was determined, and the scheduling procedures that can be applied were identified.

REFERENCES

[1] J. Błażewicz, P. Hawryluk, R. Walkowiak. "Using a tabu search approach for solving two dimensional irregular cutting problem." *Annals of Operations Research*, no 41, pp. 313-325, 1993.

[2] J. Błażewicz, K. Ecker. "A linear time algorithms for restricted bin-packing and scheduling problems," in *Operation Research Letters, no 2*, 1983, pp. 80-83.

[3] J. Błażewicz, M. Drozdowski, B. Soniewicki, R. Walkowiak. "Two-dimensional cutting problem basic complexity results and algorithms for irregular shapes." *Foundation Of Control Engeenering*, vol. 14, no 4, pp. 137-160, 1989.

[4] A. Bouziri, R. M'hallah. "A hybrid genetic algorithm for the cut order planning problem," in *New Trends in Applied Artificial Intelligence*, 2007, pp. 454-463.

[5] E. G. Jr. Coffman, M. R. Garey, D. S. Johnson "Approximation Algorithms for bin-packing," in *Algorithms for computer systems design*, 1984, pp. 49-106.

[6] R. Dighe, M. J. Jakiela. "Solving pattern nesting problems with GA employing task decomposition and contact detection." *Evolutionary Computation*, vol. 3, No. 3, pp. 239-266, 1995.

[7] K. A. Dowsland, W. Dowsland W. "Solution approaches to irregular nesting problems." *European Jurnal of Operational Research*, vol. 84, Issue 3, pp. 506-521, 1995.

[8] M. Hifi, R. M'hallah. "A best-local position procedure-based heuristic for the two dimensional layout problem." *Studia Informatica Universalis. International Journal on Informatics*, pp. 33-55, 2002.

[9] J. Jaskowski, A. Jardzioch. "Information flow in model of e-Production." *Studies and Proceedings of Polish Association for Knowledge Management*, no 60, pp. 83-95, 2012.

[10] D. S. Johnson "Near Optimal bin-packing algorithms". Ph.D. Thesis 1974.

[11] Z. Li, V. Milenkovic. "Compaction and separation Range of solutions an algorithms for non-convex polygons and their applications." *European Journal of Operational Research*, no 84, pp. 539-561, 1995.

[12] M. Zasadzień, B. Szczęśniak, K. Midor „The functioning of e-maintenance services in selected devices of the building industry." *Management Systems in Production Engineering,* no 1(9), pp. 31-37, 2013.

dr hab. inż. Andrzej Jardzioch, prof. ZUT,
mgr inż. Jędrzej Jaskowski
West Pomeranian University of Technology, Szczecin
Faculty of Mechanical Engineering and Machatronics
Al. Piastów 19, 70-310 Szczecin, POLAND
e-mail: andrzej.jardzioch@zut.edu.pl
jjaskowski@zut.edu.pl

Artykuł w polskiej wersji językowej dostępny na stronie internetowej czasopisma.

The article in Polish language version available on the website of the journal