



## TABU SEARCH AND GENETIC ALGORITHM FOR PRODUCTION PROCESS SCHEDULING PROBLEM

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**ABSTRACT. Background:** The paper deals with production process scheduling problem. In large companies, the decision-making process about operators' work, machines availability and production flow is a very difficult task, which is often being done by employees. Thus, not always the decision made is optimal in terms of cost, production time, etc.

**Methods:** As a solution, two intelligent methods: Tabu Search and the genetic algorithm have been analyzed in field of production scheduling. The aim of this work was to examine the possibility of improving presented decision-making process that is being performed when scheduling, using Tabu Search and genetic algorithms. As a result of experimental re-search, it has been confirmed that the use of appropriately selected and parameterized intelligent methods allows for the optimization of the analyzed production process due to its duration. The research was case of study performed in cooperation with company that produces components for automotive industry.

**Results:** Basing on collected and analyzed data, considered methods can be more or less successfully used in production process scheduling. Comparing both used algorithms, Tabu Search twice proposed worse solutions, the average operational time was 1.63% shorter than the actual one. In this case, better results were reached by using genetic algorithm – potential operational time was always shorter than the actual one, and it was reduced by 6.3% in total on average.

**Conclusion:** Using algorithms allowed to achieve lower workload of employees and to reduce of operational time, which were the evaluation criteria in performed research. Managers of the analyzed company were pleased with the proposed solution and declared interest in developing these methods for future. This shows that intelligent methods can find, in relatively short time, the solution that is close to the optimal and acceptable from the problem point of view.

**Key words:** production process scheduling, Tabu Search, genetic algorithm, heuristic methods, intelligent methods in manufacturing.

### INTRODUCTION

Nowadays, not only the low cost is important for customers, but also the quality of products and as quick delivery as possible [Musiał et al. 2017, Kotowska et al. 2018, Zwolińska et al. 2017]. That is the reason why companies that want to be competitive need to perform complex solutions in production scheduling area. This process should include aspects like analysis of available machines and their effectiveness, operators' availability and

possibilities, organizational restrictions etc. This is a very difficult task, that usually is being performed by one person or small group of employees. Even if companies use computer programs to schedule, the process of decision-making is often fraught with error caused by human factor, frequent and quick changes in production process. A solution of this problem is, among others, an application of intelligent methods (heuristic and metaheuristic), which can find in relatively short time, the solution that is close to the optimal and acceptable from problem point of view.

The practice confirms that heuristic methods can be successfully implemented in production processes [Kotowska et al. 2018, Górnicka et al. 2018, Burgy and Bulbul 2018, Paprocka et al. 2017]. The use of intelligent methods and algorithms in production and logistic processes are shown in many publications. Algorithms are being used in process optimization, for example in transport management [Bożejko et al. 2017], scheduling [Chen et al. 2018, Shishido et al. 2018, Bożejko, et al. 2008, Kumanan et al. 2006, Grajek and Zmuda-Trzebiatowski 2014], delivery synchronization [Gdowska and Książek 2017] or planning and helping in decision-making [Ahmad et al. 2017, Kazemi et al. 2009].

## RESEARCH PERFORMED IN INDUSTRY

The research was performed in a company that produces components for the automotive

industry. Because of the components character, most of the operations performed in the company there are welding and sealing.

## Production process

The products manufactured by the analyzed company are car seats, produced in four variants. The production plans of all variants assume mainly the use of the same machines. Production processes take place in the same production cell and there are differences between single operations. In the analyzed area of production, there are 17 machines in total, and each of them needs one operator. In the production of all four variants the unit times are the same. Data about production process flow is shown in the fig.1.

The company works in the two-shift arrangement, with 8-hours lasting workday. 15 minutes are intended to start and 15 minutes to finish the shift. Workers have two breaks, 10 and 20 minutes (fig. 2).

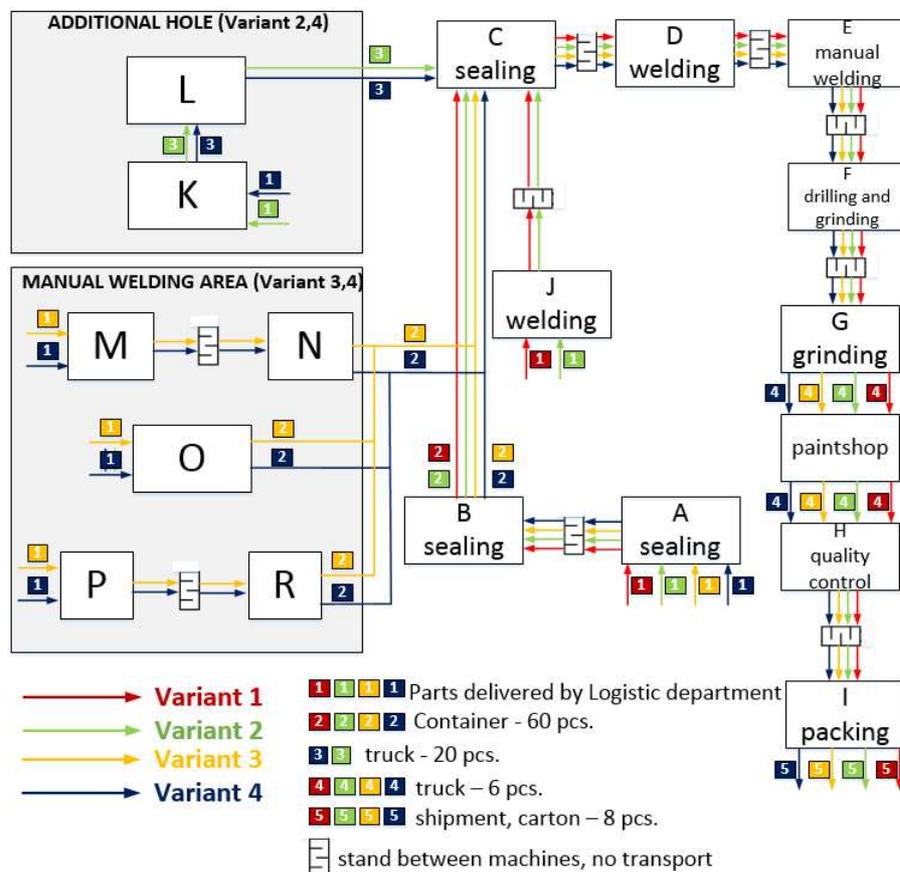


Fig. 1. Production process flow

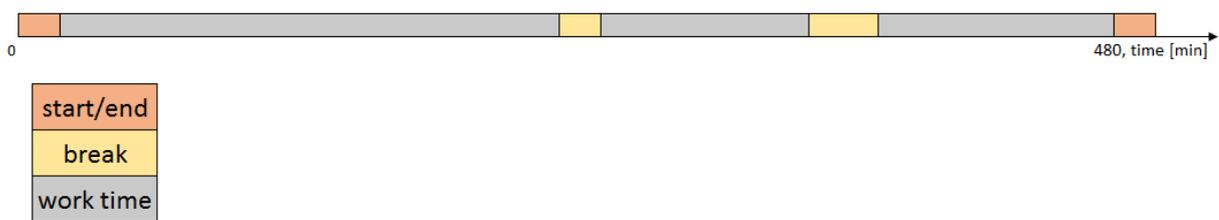


Fig. 2. Shift schedule

That means, that on one shift, the company has 420 minutes of operational time. In addition, they keep a stock of 5 pieces next to each machine with no transport before.

### Production scheduling process

Based on accepted orders, the logistic department elaborates the production plan of each shift. Then planning department calculates the operators demand, based on the sum of all unit times necessary to realize the production plan. Amount of available operators on one shift may differ than planned, because of sickness, random events or the need of using operator to help in production processes for other products. Moreover, the total amount of operators is always lower than number of machines used in production process. Each operator is allowed to work with each machine. The foreman divides the work between the operators, based on the production plan, the real number of workers and other factors. With the aim of production continuity, some workers need to operate few machines in a proper sequence. Main limiting factors taken under consideration are: limited number of employees, specified number of machines and the required operation order for each product. The scheduling process is not computer aided and it's being done in two steps. The first step is to assign operators to machines, to the load for each machine to be as even as possible. The second step is making the decision about operations sequence (if one worker operates few machines) to ensure, as far as possible, that the work flows continuously. The main aspect that determines fulfilling the schedule is the foreman experience.

## OPTIMIZATION METHODS

### Formulation of the problem

In the selected manufacturing cell,  $w = 4$  product variants from the set  $W = \{1, \dots, w\}$  are being produced. There are  $m = 17$  machines from the set  $M = \{1, \dots, m\}$ , in which  $o = 17$  from the set  $O = \{1, \dots, o\}$  operations are being executed. Each machine performs only one operation. For  $i$ -th operation, where  $i \in O$ , the operation time  $t_i$  is given. The technological process for each product is given as the sequence relation showed in the fig.1. For  $k$ -th machine, where  $k \in M$ , the initial workplace buffer  $b_k$  is given. On the  $j$ -th shift from the set  $S = \{1, \dots, s\}$ , for  $v$ -th variant where  $v \in W$  the production plan is given as a number  $p_{v,j}$  from the set  $P_{v,j} = \{1, \dots, p_{v,j}\}$  of pieces of each variant to be produced and a number  $e_j$  of available employees.

For  $i$ -th  $\in O$  operation and  $lv,j$ -th  $\in P$  piece two parameters have been determined for objective function calculation:

- start time  $t_{si,l(v,j)}$  – time, when the  $i$ -th operation for  $lv,j$ -th piece starts,
- end time  $t_{ei,l(v,j)}$  – time, when the  $i$ -th operation for  $lv,j$ -th piece ends.

The objective is to generate the work schedule for employees, specifying the beginning and end of all operation executions to minimize the entire production time.

The objective function is given as the set of two conditions:

1. Operation orders for all pieces have to be prevented.
2. End time value of the last operation for the last piece has to be as small as possible. (for all variants the last operation is “packing” on machine I).

In case of 100 pieces, the measurement of objective function is time, when machine I finishes last 100th operation).

te17,p -> min

### Selected algorithms

The research results indicate that there are many types of decision-making problems that can be solved with use of the meta-heuristic algorithms [Burduk, Musiał 2016, Górnicka et al. 2018, Ho et al. 2010, Kotowska et al. 2018, Musiał et al. 2017, Gola Kłosowski 2018, Kalinowski, Skołud 2017]. They are being increasingly used as supporting methods because they allow finding a near-optimal solution in a reasonable time and do not need the transformation into mathematical formulations [Antosz, Stadnicka 2014, Dorigo 1992, Krenczyk, Skołud 2014]. The intelligent methods are applicable to both simple and NP (nondeterministic polynomial) optimization problems [Bożejko et al. 2016, Burduk and Musiał 2016, Musiał et al. 2017]. Although their application does not guarantee finding the optimal solution, the proposed solutions can be fully acceptable from the company point of view [Bentley and Wakefield 1998, Tuncer and Yildirim 2012], because of time, labour input and human errors reduction. For the considered problem of decision-making process in scheduling it was decided to use intelligent methods. For the examined case, the Tabu Search algorithm and the genetic algorithm were considered as well known, advanced and modifiable algorithms appropriate to the investigated issue. In the Tabu Search method, it is possible to modify the sequence of tasks performed by employees. In genetic algorithm there are various selection methods that may affect speed and quality of the result. The Tabu Search algorithm has been implemented by OpenTS - a java tabu search framework. Genetic algorithm has been used with Matlab program.

### Tabu Search algorithm

Tabu Search algorithm is widely used because of ease of its implementation and high quality of generated solutions. It belongs to the group of local search algorithms.

The main advantage of Tabu Search algorithm is the possibility of avoidance of sticking in local minimum.

```
Algorithm Tabu Search (S0, var S, max_m, max_it)
Set S = S0 and n_iter = 0
Repeat
  m = 0
  best = 0
  it = it + 1
  Repeat
    m = m+1
    Execute Check_the_neighboring_solution (S,Sm)
    Execute Check_Tabu_list (S,Sm)
    if (f(Sm) > best then (best = f(Sm) and
      (m2= m))
  until (m = max_m)
  Execute Add_to_Tabu_list (S,Sm2)
  S= Sm2
  If best > solution then solution = best
Until n_iter = max_it
```

Fig. 3. Basic Tabu Search algorithm pseudocode

In figure 3 the Tabu Search algorithm pseudocode has been shown. The general concept based on searching neighboring solutions and going to the best of them. To protect from sticking on local optimum the tabu lists are used and the solution once find is not taken under consideration in further searching. Moving in unacceptable solutions (solutions that do not give a valid operation order) is risky from optimization point of view. These solutions are tabu – not visited again. Among solutions that give a valid schedule a tabu list length equal to 7 has been applied. It means that 7 last moves are tabu and tabu list is refreshed after each movement. Additionally, the longtime memory of objective function value has been used to prevent from turning around.

## Genetic algorithm

Genetic algorithm is an example of an algorithm analyzing many samples in each step, in contrast to Tabu Search based on a simple sample analysis. Genetic algorithm belongs to class of evolution algorithms. Main

limitation of a genetic algorithm are instability - lack of convergence in the absence of good schemes and premature convergence. Adjustment of parameters in a specific case may solve these problems. A scheme of genetic algorithm has been presented in the figure 4.

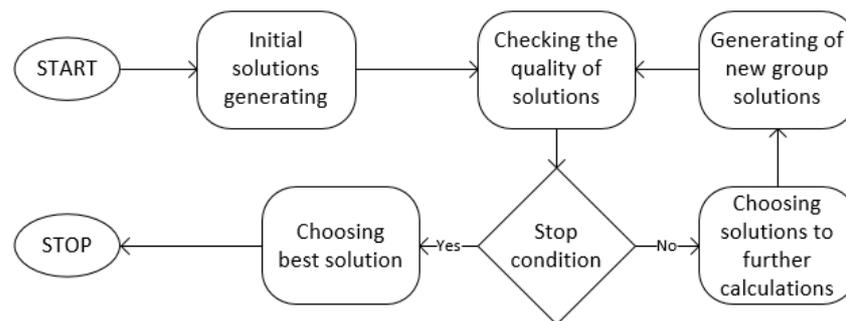


Fig. 4. Scheme of genetic algorithm

Process of genetic algorithm solution searching consists of several steps. First, called initiating, generates an initial population – initial groups of solutions. In next step, these solutions are evaluated in terms of acceptability and quality in accordance with defined objective function. Chosen solutions can be used to next population generating – next group of solutions. The algorithm is finished after knowing the stop condition, for example: after determined number of cycles or after finding the accepted solution.

## Algorithms in investigating issue

In the following example, the Tabu Search algorithm and the Genetic algorithm have been used to solve task of allocation technological operation to proper employees and establishing the order of operation execution. Order of operation will be accepted if:

1. All executed operations will be included with amount equal to number of produced pieces of each variant.
2. Given sequence of operation executing will be preserved for each piece of product.

Basing on the real process of allocation operations to employees, the Tabu Search algorithm had been used in two stages. First, to allocate employees to machines to keep the employees occupancy as equal as possible. That way, 3 best solutions have been chosen. Next, basing on solution chosen in first stage, to find the best possible sequence of executed operation for each employee. Genetic algorithm also has been used in two stages. First, to allocate employees to machines to optimize their occupancy. Next, based on 3 best solutions the operation sequences for employees have been generated.

## Comparison of methods results

The results obtained with use of both analyzed methods compared with actual results of the company are illustrated in the diagrams (fig. 5 and 6).

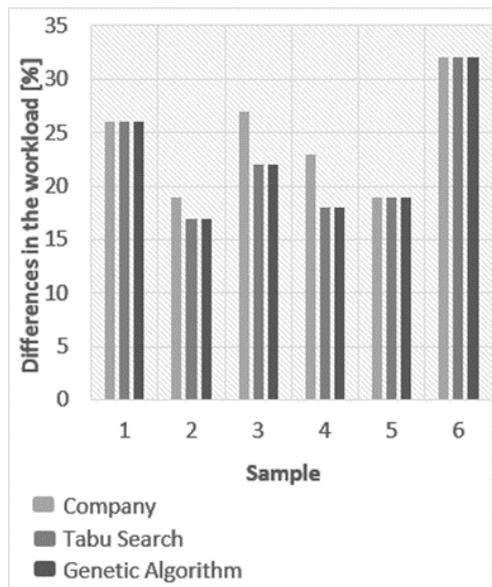


Fig. 5. Differences in the workload of employees

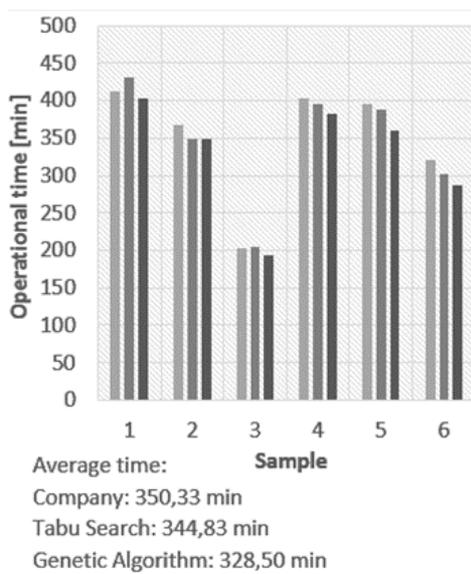


Fig. 6. Operational time of orders execution in analyzed samples

Analysis of the results obtained after the first step in solving the optimization task indicates that this task is performed by the brigadier with a very good result. In about half of the analyzed cases, the foreman assigned the machines to the employees in the same way as the algorithms proposed. In other cases, the result of the foreman was the second or third best solution proposed by the algorithms. This step was solved by both algorithms in all cases identically. Analysis of the results obtained after the second step indicates that the genetic algorithm proposed better solutions than the Tabu Search algorithm. The Tabu Search algorithm has twice proposed worse

solution than the foreman and in all studied cases showed solutions only on average 1.63% better than the actual ones. Based on the data collected, in each of the analyzed samples, the genetic algorithm suggested a solution better than the real one – potential operational time was in each case shorter, in total on average by 6.3% than the real one.

## CONCLUSIONS

In the presented work the decision-making problem in production scheduling has been considered. As a solution an intelligent scheduling system with the use of the Tabu Search method or the genetic algorithm have been proposed. The research has been carried out on an example of a company, which is a producer of components for automotive industry. The results obtained by both considered methods show that only the genetic algorithm can be successfully used for solving considered problem. By using the genetic algorithm it is possible to reduce an operational time, guaranteeing the execution of all accepted orders and minimizing the resources usage. The obtained results demonstrate high potential of the genetic algorithm usage that can be successfully used for solving similar or even more difficult problems. Therefore, further works on this method have been planned.

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## TABU SEARCH I ALGORYTMY GENETYCZNE W HARMONOGRAWOWANIU PROCESÓW PRODUKCYJNYCH

**STRESZCZENIE. Wstęp:** Artykuł opisuje problem harmonogramowania procesów produkcyjnych. W dużych przedsiębiorstwach proces podejmowania decyzji dotyczących pracy operatorów, maszyn, dostępności zasobów i przepływu produkcji jest bardzo złożonym zadaniem, często wykonywanym przez pracowników. W związku z tym podjęte decyzje nie zawsze są optymalne w kontekście kosztów, czasu produkcji itp.

**Metody:** Jako rozwiązanie, przeanalizowane zostało użycie, w obszarze harmonogramowania produkcji, dwóch metod inteligentnych: Tabu Search i algorytmów genetycznych. Celem pracy było zbadanie możliwości doskonalenia procesu podejmowania decyzji, który jest wykonywany przy harmonogramowaniu produkcji, przy pomocy Tabu Search i algorytmów genetycznych. Jako wynik eksperymentu przeprowadzonego podczas badań, potwierdzono, że użycie odpowiednio wybranych oraz sparametryzowanych metod inteligentnych pozwala na optymalizację analizowanego procesu produkcji. Badania zostały wykonane we współpracy z przedsiębiorstwem zajmującym się produkcją komponentów dla branży motoryzacyjnej, jako studium przypadku.

**Wyniki:** Zgodnie z zebranymi i przeanalizowanymi danymi, wybrane metody mogą być z mniejszym bądź większym powodzeniem stosowane w procesie harmonogramowania produkcji. Porównując zastosowane algorytmy, Tabu Search dwukrotnie zaproponował rozwiązanie gorsze od aktualnego podejścia przedsiębiorstwa, jednak czas produkcji został skrócony średnio o 1.63%. W tym przypadku, lepsze wyniki pozwoliło osiągnąć zastosowanie algorytmu genetycznego – potencjalny czas produkcji był zawsze krótszy od aktualnie stosowanego rozwiązania, a średni czas produkcji został zredukowany o 6.3%.

**Wnioski:** Zastosowanie algorytmów pozwoliło na osiągnięcie niższego obciążenia pracą operatorów oraz zredukowanie czasu operacyjnego, co stanowiło kryteria oceny w przeprowadzonych badaniach. Kierownictwo analizowanego przedsiębiorstwa było zadowolone z zaproponowanych rozwiązań. Zdecydowali się na stosowanie omawianych metod w codziennym harmonogramowaniu produkcji oraz zadeklarowali zainteresowanie rozwojem stosowania metod w przyszłości. Metody inteligentne pozwalają znaleźć, w relatywnie krótkim czasie, rozwiązanie bliskie optymalnemu i akceptowalne z punktu widzenia analizowanego problemu.

**Słowa kluczowe:** harmonogramowanie procesów produkcyjnych, Tabu Search, algorytm genetyczny, metody heurystyczne, inteligentne metody w wytwarzaniu

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