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One Machine Scheduling Problem to Minimize Setup Times: Case Study

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Abstract: **The company COFAT Mateur, specialized in the manufacture of automotive cables in Tunisia, is confronting with considerable wastes of time, resulting from the significant number of setup made daily in the cutting workshop. Thus, the scheduling of OFs, the determination of an optimal sequence, to minimize the setup time presents a relevant solution to the company.**

The scheduling problem under consideration is the problem MSDST (Makespan with Sequence Depend Setup Time), a single machine problem to minimize the makespan with presence of setup time depending on the sequence, noted $1|S_{ij}|C_{max}$. Ce problem is NP-difficult. In order to find a polynomial approach for solving this problem, we present the setup time in the form of a special structure. So, the problem MSDST is solved in a polynomial way by the algorithm of Gilmore and Gomory (noted GG).

The evaluation of the solution gave relevant results (profits). Indeed the application of the proposed solution to the data relative to the company's production program shows a 61% reduction in setup time. This presents a considerable gain. In perspective, this application will be generalized for all other machines in the cutting workshop.

Keywords: **setup time, scheduling, makespan, MSDST, Gilmore and Gomory Algorithm.**

I. INTRODUCTION

In the industrial production's filed, current trends indicate that high-performance manufacturing systems must reduce or eliminate all sources of waste (such as setup time losses). Machines must be operated at full capacity. In this context, theproduction planning's optimality in terms of real-time control of these machines is becoming increasingly the major concern of any industry.

Under these conditions, the determination of a rule for scheduling and assigning the various production orders to each machine is today a worrying problem for manufacturing system's optimization, the case of the company Cofat Mateur. In fact, this company, which is specialized in the manufacture of automotive cables in Tunisia, is confronting with considerable wastes of time, resulting from the significant number of setup made daily in the cutting workshop. Thus, the scheduling of manufacturing order to minimize the setup time presents a relevant solution to the company.

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II. PROBLEM AND SOLUTION DESCRIPTION

A. *Problem Description*

The scheduling problem under consideration relates to the scheduling of the cutting orders to obtain an optimal sequencing of the working orders to maximize machine exploitation with a minimum setup time.

This is the MSDST problem (Makespan with Sequence Depend Setup Time), a single machine problem to minimize the makespan with presence of setup time depending on the sequence, noted $1|S_{ij}|C_{max}$, as in [1]. The problem objective is to maximize the machine availability to offer an optimal use of machine capacity. The criterion to minimize is the makespan. However, there's an important waste of time due to the significant number of setup made daily in the cutting workshop. Then, the problem is the minimization of the makespan with presence of dependent sequence setup time.

This problem is NP-hard, as in [1], and is equivalent to a traveling Salesman Problem (TSP). In fact, a working order, noted as OF, i can be considered as a city i, and the setup between two OFs i and j can be considered as the distance between the two cities i and j. More precisely, the MSDST is similar to an antisymmetric TSP because the setup is sequence dependent, as showing in [4].
For this problem, each OF i is characterized by a processing time p_i, and a setup time S_{ij}. Thus, if a OF j is executed on a machine after an OF i, then an installation time (time need for the machine preparation) S_{ij} is required.

B. *State Of The Art*

The problem considered in this paper is NP-hard [1]. For this reason, several resolution methods in operational research are developed. On one hand, there are the exact methods and the approximate methods. Indeed, the exact methods are able to find optimal solutions for small size problems and encounter most many difficulties for large size problems (Linear Integer Programming [5], Dynamic Programming [5], Branch & Bound algorithm [6] and Gilmore & Gomory algorithm [2]). On the other hand, the approximate methods do not guarantee to find an exact solution, but an approximation of the optimal solution. Dispatching rules are used such as the Shortest Setup Time (SST). Many metaheuristics are developed: the ant colonization algorithm, the genetic algorithms and the Tabu search method [3].

However, a company is always looking for methods giving optimal solutions in reasonable computation time. In order to find optimal solution in a reasonable time to resolve the MSDST, we present the setup time in a special structure [4].

C. *Solution Approach*

The problem $1/S_{ij}/C_{max}$ is NP-hard. In order to find a polynomial approach for solving this problem, the setup time between two jobs i and j is expressed in a special structure: $S_{ij} = | f_i - e_j |$ as detailed in [4].
Where: e_i, presents the machine state needed for the execution of the OF i. and f_i, presents the machine state after the execution of OF j.

So, the problem MSDST is solved in a polynomial way by the algorithm of Gilmore and Gomory, as shown in [2]. Details of the procedure are described in [4] and the steps of the algorithm are given in the Appendix A. In fact, this algorithm is very efficient with complexity of O (n ln (n)), as illustrated in [4]. This algorithm takes into consideration, for each OF i, the two input parameters f_i and e_j. These two parameters are treated throughout the algorithm following a well-defined procedure. In fact, this algorithm is summarized in seven steps. All these stages revolve around the graphs theory's notion and the operations of sorting and grouping.

In order to determine e_i and f_i, all the setup operations needed for a OF i are identified and measured : changing the wire, the marking, the tool for crimping the two contacts, the tool for sealing the joint, the type of end piece and checking the crimping height. Then, ei of each OF is considered (which is a reference wire to cut) and calculated based on the working order characterization: the type of its two contacts, the type of seal, and the type of the tip and the type and marking of the wire. The final ei is the duration sum of all the operations duration of the needed tasks.

After the OF i execution, the machine keeps the same settings made during the setup operations. So that, the final machine state f_i, is considered as the same state of the machine e_i to which we add the machine cleaning time:

$$f_i = e_i + \text{cleaning machine time} \quad (1)$$

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Subsequently, the parameters relative to each wire reference will be calculated in the same way. Then, a series of daily OFs are used for the solution developed evaluation. Experimental Results of the Gilmore and Gilmore algorithm is coded in C++ Microsoft Visual Studio Ultimate 2013 language. The solution developed is applied to the overloaded cutting machine Komax Y. Tests are conducted on daily scheduled working orders over a series of thirty OFs with a total sequence's setup time of around 87 minutes.

The setup time of this optimal sequence is 55 minutes. Thus, the estimated gain for this series, representing the difference between the current setup time and that obtained by the scheduling application, is around 87 minutes. The cutting workshop works in two shifts, then this gain will be doubled.

So the evaluation of the solution obtained by this new application gives relevant results (profits). Indeed, the application of the proposed solution to the data relative to the company's production program shows a gain of 87 minutes/shift, which is similar to a daily gain of 174 minutes. And then, this application allowed us to benefit from a gain of 1827 minutes while reducing the setup of 61 % and increasing TRP (TRP measures the efficiency to which the site uses capacities when they are on a scheduled production) of this machine to 18%. This generates to the company annual earnings of around 37170 €. This presents a considerable gain.

In perspective, this application will be generalized for all other machines in the cutting workshop. The cutting workshop has 21 machines and each one can execute up to 60 OFs. , an annual gain of 1827 minutes can be obtained and in this case an annual gain of more than 131544 € will be realized.

III. CONCLUSIONS AND PERSPECTIVES

This paper treats a single machine problem in the company COFAT Mateur, specialized in the manufacture of automotive cables in Tunisia. The company looks to minimize the makespan with presence of setup time depending on the sequence.

As this problem is NP-difficult, setup times are expressed in a special structure, to be solved in a polynomial way by the algorithm of Gilmore and Gomory. The use of the proposed solution offers to the company a reduction of 61% in setup time and an increasing of 18 % in the TRP of the machine.

In perspective, this application will be generalized for all other machines in the cutting workshop, which will be more beneficial to this company with a gain around 131544 €.

Appendix A: Gilmore and Gomory Algorithm [4]

The Gilmore and Gomory algorithm takes into consideration, for each production order i, two input parameters f_i and e_j. These two parameters are exploited throughout this algorithm as following:

1. Renumber each production order i to satisfy $f_j \leq f_{j+1}$ after classifying them in an ascending order.
2. Sort e_j in an ascending order then calculate $e_{\Phi(j)}$ and deduce $\Phi(j)$ for all j.
3. Calculate the cost of the arc (j,j+1) as showing :
$$C_{j,j+1} = max\left\{0, \{\min\left(f_{j+1},\ e_{\Phi(j+1)}\right) - max(f_j, e_{\Phi(j)})\ \}\right\}$$
4. Construct the graph G (n, (j,$\Phi(j)$)).
5. Add arcs to this graph in order to obtain a graph composed from a single element.
6. Divide the previously added arcs into two groups such that the first group is characterized by $f_j \leq e_{\Phi(j)}$ and the second by $f_j > e_{\Phi(j)}$.
7. Determine the indexes $j_k and t_k$ such as :
$$\begin{cases} (j_k, j_k+1) \in \text{G1} \quad \text{et} \quad j_k > j_{k+1} \\ ((t_k, t_k+1) \in \text{G2} \quad \text{et} \quad t_k < t_{k+1} \end{cases}$$

And finally the optimal sequence is obtained by calculating $\Psi^*(j)$as illustrated in this formula:

$$\Psi^*(j) = \Phi(v)$$
$$= \Phi(\alpha_{j_1,j_2}\alpha_{j_2,j_3} \dots \alpha_{j_k,j_{k+1}}\alpha_{t_1,t_2}\alpha_{t_2,t_3} \dots \alpha_{t_k,t_{k+1}}$$

$$\text{Where}\begin{cases} \alpha_{pq}(j) = j si j \neq p, q \\ \alpha_{pq}(p) = q \\ \alpha_{pq}(q) = p \end{cases}$$

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