Possibility of Implementation a Real-Time Production Planning System to Reduce the Environmental Impact of the Production Line in Tthe Case of Tthe Electroplating Line

Mikołaj Grotowski[1]

[1] AGH University of Science and Technology, ul Antoniego Gramatyka 10, Kraków, Poland

Abstract
The industry now has to increasingly reduce its negative impact on the environment. This is due to both the growing environmental awareness of consumers and the "European Green Deal" policy and the preceding "Circular Economy" policy. One of the methods of reducing the negative impact on the environment is the optimization of the production process. In the case of electroplating lines, optimization problems of this type are included in the "Hoist Scheduling Process" (HSP) category. Previous research on the optimization of this type of processes has focused solely on the aspect of increasing efficiency. This work presents the problem of creating a multi-criteria algorithm that comprehensively improves the production process, also optimizing it in terms of its overall impact on the environment. The current proposals for solutions to HSP class problems have been presented, which additional factors must be taken into account in the approach consistent with the Circular Economy and with the use of which parameters we can regulate such a process.

Keywords
HSP, Circular Economy, European Green Deal, RHSP

1. Introduction

The electroplating processes are carried out on specific production lines. They are different for two reasons. One is the limitations of the physico-chemical processes used during production, the other is specific solutions for transporting products inside the line.

1.1. The specificity of the electroplating line

In the electroplating plant, the products must be bathed in special tubs (tanks) containing various electrolytic baths. An example of such a line is shown in Figure 1. For each product, the processing (dipping) sequence is known in advance and includes three steps: preparation operations (part cleaning and rinsing), metal coating operations, and finishing operations (rinsing, passivation and drying).

Bathing operations in bathtubs must not be interrupted. The duration of each of them has a set minimum and possibly maximum length, due to the requirements of the technological process; for example, the thickness of the coating depends on the area to be coated, the concentration of the bath and the amperage. When the operation time is shorter than the minimum value, the coating will be too thin; if it exceeds the maximum length, the parts may be damaged or the production cost may increase because too much metal is deposited. Some operations only have a minimum time, no maximum time; which means that the product can spend any time in the bath. Other operations have a strictly defined execution time, i.e. the minimum and maximum times are the same.

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EMAIL: mikolaj.grotowski@agh.edu.pl (A. 1)
ORCID: 0000-0002-0313-670X (A. 1);

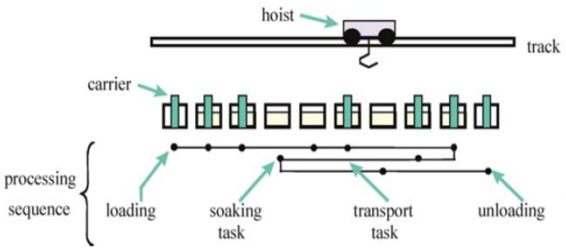

Figure 1: An example of an electroplating line (Manier and Bloch, 2003)

Each operation is performed in one bathtub. The product may require the same operations to be performed several times, so it can be placed in the same bathtub several times. Such a bathtub is referred to as multifunctional; the other bathtubs are single-functional.

When the bathing time in a certain tub is much longer than in others, such a bath can be duplicated, which means that it has more than one available space for a product, or that there are several bathtubs in which the same operation is performed (so-called parallel baths). processing of multiple products).

Product processing begins with loading onto a carrier (PCB frame, basket or bolt barrel). Then, handling and transport devices (cranes or hoists) move the carrier from the bathtub to the bathtub. All cranes are identical. They move along one track (above the bathtubs), so they cannot pass each other.

The transport operation consists of several stages. First, the crane moves empty from its current location to the tub containing the carrier to be transferred. Here it grabs the carrier, lifts it above the bathtub and stops so that the electrolyte can drip off (to reduce contamination of subsequent bathtubs). It then carries the carrier to the next tub in the appropriate sequence for that product. Here the crane stops again to stabilize itself and lowers the carrier to immerse it in the new tub. After that, the crane is free and can perform another transfer operation. During some bathing operations the crane must remain over the bath to hold the product; thus, in the course of such operations, both the tub and the crane are occupied.

Figure 2 (Feng et al., 2015) shows an exemplary schedule with all types of operations: product transport, empty runs, product processing (baths); the loading / unloading station 0 and the tubs 1-6 are lined up in the order shown in the diagram, and the order of the baths is according to the numbers of the tubs. In this diagram, there are three product types A, B and C. The numbers indicate consecutive items of that type. Products A1, A2 and B1 are in the process of bathing at the initial schedule; during its duration, at the loading station 0, the production of the products A3, B2 and C1 (marked with colors) begins.

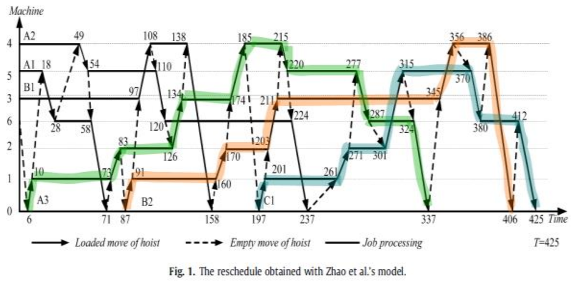

Figure 2: Gantt diagram of a sample schedule (Feng et al., 2015)

When the crane stops for a moment above the bathtub, while the product is immersed and taken out of the bathtub (time to drip the products or stabilize the crane), both the crane and the bathtub are busy. If this time is very short, it can be omitted or added to the time of transport or bathing operation (this is what their publications say). If this time is too long for this, the schedule of transport and bathing operations will have to overlap.

All transport times are known in advance. The planning procedure must take these into account as they are as long as the processing times. No breaks in the operation of the crane are allowed during the transfer of the carrier, with the exception of the dripping and stabilization stages, the durations of which are known. Other breaks may damage the products, e.g. by oxidizing the surface of the products for too long.

In a simple system, there is one line and all transport operations are carried out by cranes traveling along one track along the line. The complex system consists of several parallel lines and includes additional cranes for transverse transport (between the lines). The synchronization of cranes moving along and between the lines must be ensured.

Scheduling is generally intended to maximize productivity, production volume per unit of time, eg per hour or shift. Sometimes other optimization criteria are taken into account, e.g. maximization of the degree of use of selected resources, or minimization of product completion times.

Scheduling may also aim at the robustness of the schedule, defined as its resilience to random fluctuations in operation times. It enables the schedule to be performed without any changes (under all technological conditions). Reliability can be achieved through time buffers of all operations (schedule clearances, planned machine and product downtime), which ensure timely commencement of subsequent operations despite delays in previous operations. A robust schedule might possibly allow for minor timing changes (operation start times), but the sequence of operations and resource allocation would remain unchanged. If the schedule is not reliable and an operation is delayed, it is usually necessary to change the schedule remaining to be performed.

Regardless of the optimization goal (criterion), it should be achieved while observing all technological conditions of the process, namely the limitations related to the processing sequence, the minimum and maximum limits of processing times, the capacity of resources (tubs, cranes and carriers) and the time during which the crane must lower the carrier into the bathtub between two successive transport operations.

The planning of bathing and transport operations in electroplating plants is known in the literature as the hoist scheduling problem (HSP). At the same time, the schedule of the crane's movements determines a certain schedule of the processing (bathing) operations. Within the so-called The scheduling theory, this problem belongs to the group of scheduling tasks without waiting (between operations) and without interrupting the operation.

1.2. Algorithm classification

Highlighting task classes in the literature

1. Cyclic hoist scheduling problem (CHSP) consists in determining a cyclically repeated sequence of crane movements:
- The number and type of products are known in advance and the same in each cycle.
- It is necessary to minimize the length of the transition phase between two consecutive production cycles (schedules).

The simplest and best-described variant is the Cyclic hoist scheduling problem (CHSP). It occurs when we assume that the subsequent production cycles are the same, and the last element of the cycle is followed by the first one again. This allows you to plan production for larger orders, when we know in advance what products we want to put on the line and in what number. Numerous proposals for solutions to this variant can be found in the literature.

2. Predictive hoist scheduling problem (PHSP) consists in setting the schedule for the next time period, shift or day:
- The number and type of products to be made in a given period are known in advance, but different in each subsequent period.
- It is necessary to take into account the initial state of the system at the beginning of a given period.

3. The dynamic hoist scheduling problem (DHSP) is the computation of a new schedule for all operations every time a new part enters the line.
- The number and type of products to be made are not known in advance, new orders for products appear unexpectedly already during the execution of the schedule.
- The schedule for making earlier products may be changed.

Another variant is the "Dynamic Hoist sheduling problem" (DHSP). It occurs when orders change over a short period of time, which makes it impossible to use one repeated cycle of introducing products to the production line. Along with the change of orders, the order of placing products on the line and the sequence of transport operations should be dynamically changed. The plan is defined at regular short intervals and adapted to current needs. In the literature, you can find several examples of algorithms that meet the requirements of dynamic scheduling.

4. Reactive hoist scheduling problem (RHSP) is the real-time scheduling of upcoming operations where the cranes must be dynamically assigned to subsequent transport operations. Third level heading

The last option is the " 4. Reactive hoist sheduling problem" (RHSP). In this variant, the schedule is created and modified on an ongoing basis. This allows not only to smoothly adapt to current orders, but also to react to random events on the production line. Until recently, it was not possible to create such algorithms due to the complexity of calculations and limitations in the capabilities of computers. It seems, however, that the development of both computer hardware and computational methods allows the conclusion that algorithms RHSPs are now possible to create. The first articles about them appear, but so far no working RHSP algorithm has been published.

1.3. Variants of production lines

There are various configurations of production lines with transport cranes. The line with one conveyor is the easiest to describe in the algorithms. (Fig 1) Most of the algorithms in the literature it refers to such a configuration. However, there are often other variants in actual lines. A very common variant is one in which the line has two cranes moving on common tracks. This means that although in theory both cranes have access to the entire line, it is currently limited by the location of the second lift. This is due to the fact that the cranes cannot pass each other (Fig. 2). Another variant is that there are two cranes, but they have their own track sets and are mounted in a way that allows them to pass each other, this arrangement also occurs in two variants, in one of the cranes can always pass each other, and in the other one of them (external) must not carry the load when passing. These variants of settings are especially difficult to implement in algorithms. Other variants are lines with two conveyors, in which each conveyor has its own separate section of the line that serves and variants with more conveyors.

1.4. Changes in the structure of the problem resulting from the environmental approach.

The basic change in the environmental approach is that instead of a single criterion, i.e. line productivity, optimization must be multi-criteria. Productivity continues to be the primary criterion as it determines both the economic efficiency and the ecological cost of the energy used. However, there are additional criteria, such as the rate of consumption of solutions, the degree of possible use of the solutions or the possibility of utilizing the active substance after the end of production.

The second important change is that, apart from the order in which the products are put on the line, we also use the parameters of individual processing steps, such as solution temperature, concentration, process duration or current characteristics, as production control variables. These variables are partially dependent, for example the reduction of the process time may be due to the fact that it is carried out at a higher temperature or by using a solution with a higher concentration.

These changes not only make the NP problem difficult, like all HSP problems, but also make it non-linear.

1.5. Conditions that must be met in order to be able to apply the algorithm to reduce the impact of production on the environment.

Due to the fact that many process parameters that the algorithm is to control are relatively dynamic, it seems that only RHSP class algorithms can give the appropriate effect. This is due to the fact that the existing galvanizing lines do not provide for continuous control of these parameters, but only periodic corrections. Hence, for example, the algorithm can determine the initial concentration of the solution, but it should modify the parameters on an ongoing basis when the concentration changes during the production of one batch of products. It should accordingly regulate the time of individual operations, and with its change, the sequence of subsequent products.

Due to the complexity of the calculations, it should divide the calculations into parallel threads, thanks to which it will be possible to use the methodology of parallel processing. Due to the fact that most of the electroplating lines do not have high-power computing facilities, an interesting option seems to be the optimization of calculations in terms of the use of GPUs of PC computers. The challenge in creating an algorithm in this way is the division into independent functions and adapting the computational part to the specific capabilities of graphics cards.

2. Conclusions

As presented, the problem of using heuristic algorithms to solve HSP-type tasks under the "Circular Economy" problem has not found a satisfactory solution to date. However, the analysis shows that it is possible to construct such a solution. Previous tests on the laboratory simulation scale show that although the algorithms described in the literature are not sufficient to solve the problem, they can be a starting point for further research. Simulation tests of the algorithm based on the work of Henrik J. Paul, Christian Bierwirth, Herbert Kopfer, (2007) with the author's further development showed that he is able to develop solutions for individual production batches. Its further development should enable work in real real time, which will enable the implementation of multi-parameter control and multi-criteria evaluation. With the growing environmental requirements for production processes, it seems that the implementation of this type of solutions is a real and relatively cheap solution to reduce the impact of production processes in electroplating on the environment.

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