MODELING AND SIMULATION OF THE PRODUCTION PROCESS OF A METAL SLITTING LINE

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ABSTRACT: Modeling and simulating the production process of a metal cutting line consists in creating a virtual representation of the process and analyzing its behavior in scenarios. The objective of this study is to improve the process by identifying inefficient activities and optimizing the involved parameters. To create a model of the production process of a sheet metal cutting line, factors such as workers, specifications of the machines and slitting process parameters (such as cutting length) are considered.
Simulating the production process of a metal cutting line can help identify possible problems such as wear of cutting knives, excessive force on the material, displacement of knives from specified positions, etc. Simulation can be used to adjust process parameters, improve the quality of sheet metal cuts and reduce waste.

KEYWORDS: modelling, simulation, production process, slitting line

1. Introduction

Present paper refers to modeling and simulating the production process of a metal cutting line, with the main purpose of identifying inefficient activities and optimizing the parameters involved by simulating various production scenarios. This study is also based on two internships carried out by the author at *voestalpine Steel Service Center Romania* which is globally leading steel and technology group with a unique combination of materials and processing expertise (500 companies in the group, 50 countries, 5 continents), with an annual production capacity of 130,000 tons (over 2 million tons globally), the lines within this company having a limit of 35 tons per coil, processing material with thicknesses between 0.3 and 6mm, the unrolled rolls having lengths averaging 4000m. For packaging, only 60% of orders use standard euro-pallets, the company having advanced logistics solutions through which pallets are produced for atypical orders so that a variety of products can be manufactured and delivered according to customer specifications.

Fig. 1 Metal slitting line from Fagor Arrasate company [7]

The production process of a metal slitting line is a manufacturing process used to cut large rolls of sheet into narrower strips. The process involves feeding a sheet coil through a slitting machine, which is equipped with circular blades set to the desired width. The blades cut the sheet into strips, which are then wound onto separate rolls. This process requires lines of machines equipped with a coil unwinding machine, a sheet leveling machine, a sheet cutting machine, and a sheet rewinding machine into rolls.

2. Model Definition

The formulated model refers to the activities of the plant where the processes of metal slitting and cut to length are carried out.

Fig. 2 Industrial factory of *voestalpine Steel Service Center* [4]

From an equipment standpoint, two sheet cutting lines are used: one line is for cutting steel rolls into narrower width coils (slitting), while the other is for cutting steel coils into sheet at a specified length. The supplier of these lines is Fagor Arrasate, along with other equipment used in the company, such as packaging systems, the system for handling stored coils, automated quality control tools, etc.

From a shift perspective, the activity is carried out in two shifts, from 6:00 a.m. to 2:00 p.m. and from 2:00 p.m. to 10:00 p.m. In principle, both lines are used at maximum capacity in the first shift, with the steel cut to length line being used the most in the second shift.

From a human operator standpoint, due to the degree of automation in the processes, operators are primarily needed to adjust the machine parameters according to the customer order specifications. The role of the semi-finished products obtained by cutting steel coils into narrower coils and/or sheets is very important because they meet the needs of industries such as automotive, construction, or where cold plastic deformation processes such as stamping and/or deep drawing are used, using such semi-finished products as raw materials.

In order to model a metal cutting line, the following simplifying assumptions have been applied: the materials are uniform, without defects or major deformations, the sheet loading process is automated and does not require human intervention to be executed, cutting is done in a single pass, all measuring and control devices are compliant, and the resting times and needs of human operators are neglected.

To model the sheet cutting process, the following set of variables and parameters will be used: the length of the sheet (L) - variable, the width of the sheet (W) - variable, in accordance with the limits of the line, the thickness of the sheet (T) - variable, in accordance with the limits of the line, the weight of the sheet (G) - variable, depends on the properties of the coil, the sheet loading speed - parameter of the coil-unfolding machine, the cutting speed - parameter of the sheet cutting machine, the speed of retrieving the resulting sheets - parameter of the automatic sheet retrieval and packaging system. The process times are as follows: the time for changing the coil to be cut, the time for unfurling the coil, the cutting time, the time for evacuating the piles of sheets from the material flow zone, the total cycle time. [5]

The model uses the following variables and parameters: the total length of the sheet obtained from the steel coil, the width of the sheet, the thickness of the sheet, the number of cuts, the minimum and maximum cut length, the maximum height of the stack of the resulting sheets, the maximum weight supported per stack of sheets, the material's tensile strength, density, and weight of the sheet.

Based on practical experience from internships, the following simplified model has been developed:

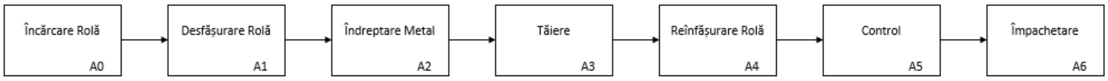

Fig. 3 IDEF diagram of the metal slitting process

Since the coil can be straightened immediately after enough metal has been unwound so that it can be taken over by the straightening machine, and, analogously, the metal can begin to be cut from the moment enough material from the straightening machine of the line has reached the cutting machine (where there are specialized circular knives for cutting the metal), a simplified diagram of the process flow has been created.:

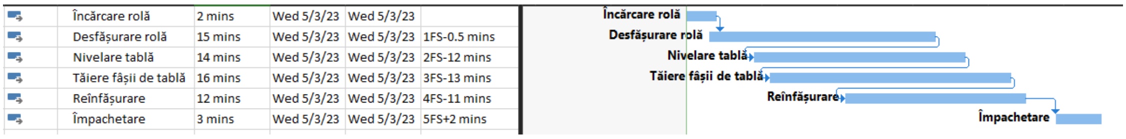

Fig. 4 Diagram of operations in the process of metal slitting.

3. Data Acquisition and Analysis

Based on the author observation and analysis from internships at the company *voestalpine Steel Service Center România*, through direct contact with the production process flow and with information received from the company's experts, information regarding the production cycle have been gathered.

For the slitting line, Table 1 presents the operations and resources required for the relevant metal slitting production process.

Table 1. Metal slitting process

Operation	Machine	Operator
Loading of coil	Coil Entry Machine	Line Entry Operator
Uncoiling of coil	Decoiler Machine	Primary Operator 1 or 2
Straightening of coil	Straightener Machine	Primary Operator 1 or 2
Cutting of coil into narrower coils	Slitter Machine	Primary Operator 1 or 2
Rewinding of sheets back into coils	Recoiler Machine	Primary Operator 1 or 2
Packaging	Automated Packaging System	Packaging Operator

For the steel coil cutting line, Table 2 presents the operations and resources required for the production process of the metal slitting line.

Table 2. Metal cut to length process

Operation	Machine	Operator
Coil loading	Coil entry machine	Line entry operator
Uncoiling	Uncoiling machine	Main operator 1 or 2
Straightening	Straightener machine	Main operator 1 or 2
Sheet cutting	Sheet cutting machine	Main operator 1 or 2
Packaging	Automated packaging system	Packaging operator

4. Simulation Software

In order to simulate the production process of a metal slitting line, the Siemens Tecnomatix Plant Simulation 2201 simulation software tool was chosen. The main features of the production system simulation software tool are: the capabilities to synchronize the simulated process with a real factory (Digital Twin) [6], the capabilities to navigate through well-structured hierarchical 3D models of production facilities using high-performance virtual reality equipment such as SteamVR, Oculus Rift, Windows Mixed Reality, etc., integration into an open system architecture for compatibility with interfaces and integration capabilities, such as ActiveX, C, CAD, COM, JSON, ODBC, Oracle SQL, Socket, XML, etc., free analysis and experimentation through built-in tools and graphical outputs for evaluating the performance of production systems, including automatic obstacle detection, output analysis, machine capabilities, resource utilization, energy consumption, cost analysis, Sankey and Gantt diagrams. Tecnomatix Plant Simulation

2201 uses integrated experiment management tools and neural networks to enable comprehensive experiment development and automatic system optimization through genetic algorithms. [8] The necessary steps for modeling representation are as follows: acquisition of process and resource information, defining machines and their parameters (auxiliary, basic, preparation-conclusion, maintenance times, etc.) and connecting them based on process sequence, defining workstations and required competencies, defining human resources, assigning human resources to machines, updating CAD machine models (current stage). The data resulting from the Tecnomatix Plant Simulation 2201 program has a variety of representations, the most common being the Chart type.

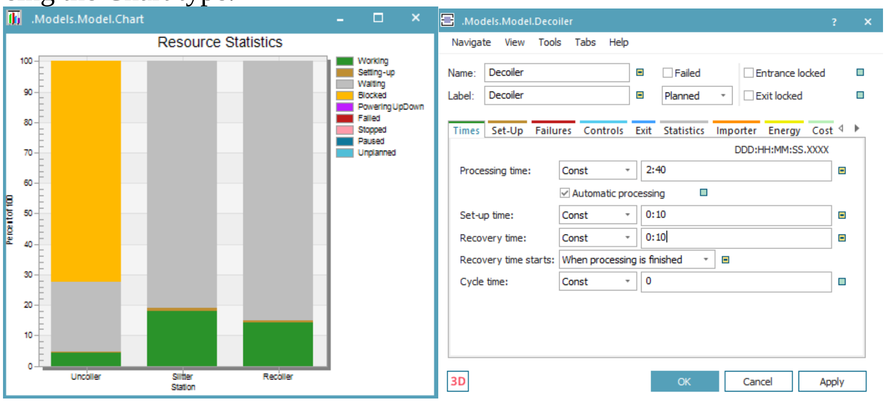

Fig. 5 Representative data for resource usage in simulation and machine parameter editing dialog

The current stage of the simulation does not yet take into account random variables, machine maintenance times, order variations, etc.

The proposed model was chosen based on the practical experience stage at *voestalpine Steel Service Center Romania* and simplified in a form that allows highlighting the stages of the sheet cutting process. The simplified model of the sheet cutting line in Figure 5 consists, in the following order, of a source (representing the system for retrieving coils from the warehouse to the feeding point of the line), the coil unwinding machine, a representation of the accumulated area of the unwound material, the sheet cutting machine, the waste collection machine, the resulting coil rewinding machine, and a Drain object, which replaces the automated packaging area of the production line.

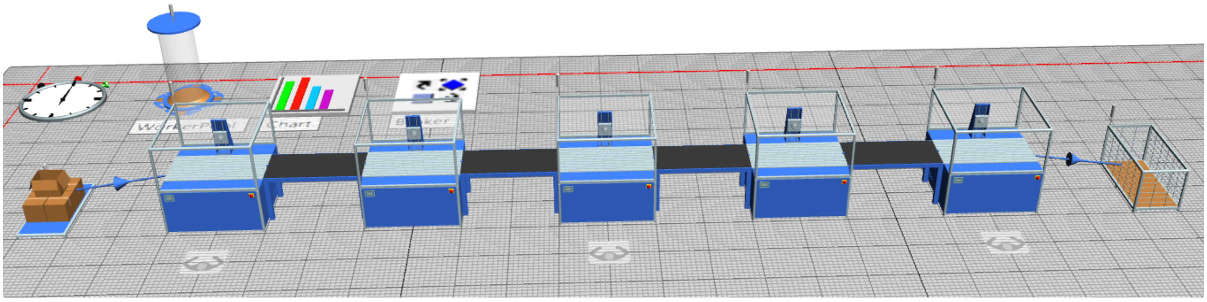

Fig. 6 Simplified model of a metal slitting line.

Based on the simplified model and by using CAD models for the CINSER company's steel slitting line obtained from online sources, relevant initial parameters for the simulation were established. The model was reconfigured so that the placement and parameters of the machines were in accordance with the real model present in the section where the practical stages were carried out. In order to configure the machines with customized graphical representations, the CAD files were imported using the Import Graphics function, and then the graphic model was transformed into a processing station (Make Simulation Object), for which specific machine parameters were established (times, resources, predecessors, etc.).

The machines in Figure 6 are the following: 1 - coil feeding machine, 2 - coil conveyor, 3 - coil unwinding machine, 4 - sheet leveling machine, 5 - coil cutting machine, 6 - automatic packing system for the resulting stacks of sheet coils.

The current research is limited by the fact that simulation programs, despite being a valuable tool for decision-making, is only utilized to a limited extent. This is considered a drawback as these programs have the potential to enable analysis and optimization of all production logistics processes, including interoperation storage and transport, among other possibilities [3].

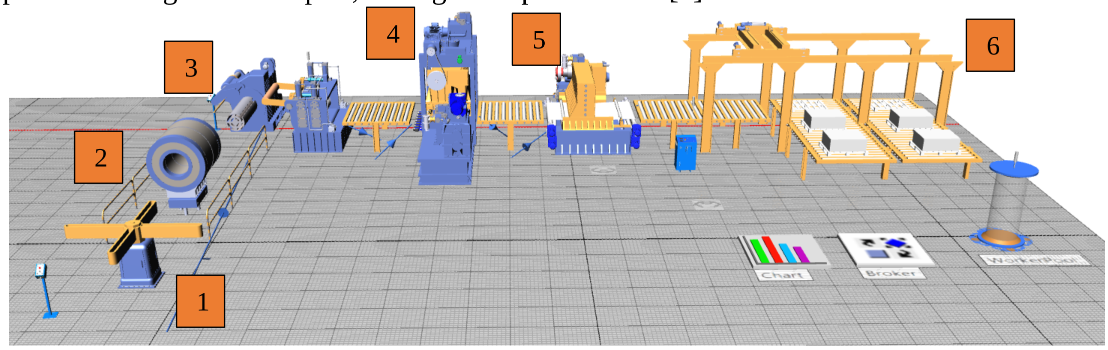

Fig. 7 Model based on CAD files from CINSER's cut to length line

5. Planning and Running the Simulation

The method of choosing the variation intervals for the input variables: based on the information obtained during the internship period along with the formulas used for estimating process times, the following variation intervals were established for a generic order (coil weight: 25t, coil width: 1000mm, sheet thickness: 0.4mm, material: cold-rolled steel, cutting length: 1m):

1. Line feed speed: taking into account that the maximum speed of a cutting line from Fagor Arrasate company is 120 m/min, a speed of 100 m/min will be chosen since the chosen material is considered defect-free and has a thickness of 0.4mm, which facilitates cutting at high speeds.
2. Feed speed (or cutting speed): this must be chosen based on the desired cutting length and the set feed speed, using incompatible settings can lead to waste because the time required for the cutting to be successfully completed must be taken into account. Since the selected cutting length is 1m and the sheet cutting machine can perform a maximum of 180 cuts per minute [7], a cutting speed of 100 cuts per minute will be chosen to synchronize the feed with the cutting and avoid adding idle times.
3. Pressing force: this must be chosen according to the thickness of the material to ensure precise cutting (according to specifications). Since a 0.4mm thick steel coil is used, a pressing force of 10 tons will be chosen.

6. Analysis and Interpretation of Results.

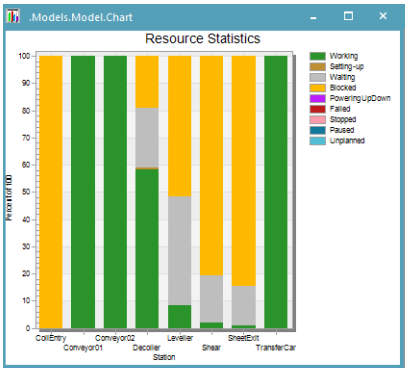

Fig. 8 The resulting data regarding the resource utilization within the simulation

According to the graph in figure 5, the following specifications were concluded regarding the current stage of the simulation model:

1. The Coil Entry object (source object, which simulates the entry of new coils into the system) was 100% blocked throughout the simulation, which is impossible to achieve in practice due

to the variability of orders and waiting times for coils to arrive from the warehouse to the processing line.

2. Conveyor01 and Conveyor02 objects worked at 100%. In reality, they need to rest for a few moments during cutting to ensure the prescribed cutting precision, automatically by the machine's sensors.
3. The Decoiler object, representative of the machine that unwinds the material coil for cutting, worked only 58.33% of the time. In reality, the coil is processed while it is unwound, which suggests that the simulation, at the current stage, does not take this into account.
4. The Leveller object (which simulates the material leveling machine), analogously, was not presented as being in operation throughout the cutting.
5. The Shear object (the cutting machine) was found to have worked only a fraction of the total processing time, which is almost true to reality because cuts are made only once every meter of material.
6. The Sheet Exit object (automatic packaging system) also worked a realistic amount of time, being activated only when the current pallet on which the sheets of metal are sent reaches either the maximum weight of the machine or the maximum weight set by the operator.
7. The Transfer Car object was shown to work constantly during the simulation. In reality, its activation time depends on the distance traveled and the coil loading system's capacity, which is typically four coils.

7. Conclusions

Based on the experience gained during the two internships, the following main stages were identified: the sequence of activities within the processes we observed at voestalpine Steel Service Center Romania was established, the parameters and resources used in the activities of the processes were determined, a simplified model of the process was created based on the real model found in the factory, and the processes carried out in the factory were partially simulated. However, the simulation has the following vulnerabilities: the simulator does not take into account certain real variables, the process needs to be simplified, and the activities cannot be carried out in parallel, the graphical representations are generic. In the near future, the aim is to implement an appropriate graphical representation and accurate simulation of the process. Furthermore, the development of a complete portfolio of useful tools for simulating processes with real materials is desired, so that the Digital Twin functions of the Tecnomatix Plant Simulation 2201 software tool can be used for greater accuracy in simulation, the model can be used within the company, and industry-specific functions of Industry 4.0, such as the Internet of Things (IoT) Engineering, can be implemented.

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