Abstract — Discrete-event simulation has been widely deployed in the manufacturing industry in order to solve problems like: finding bottlenecks, validating plant layout, finding plant stocking policy, measuring production capacity and planning/controlling the production. However, regarding to Production Planning and Control, simulation is not being used on a short-term basis. This work aims at using the previously proposed PPSS (Production Planning System based on Simulation) to evaluate a short-term rescheduling achieved by modifying products input sequence. The paper presents various simulation and production times according to different sequence inputs and machines’ breakdown, drawing some conclusions of the PPSS deployment.

I. INTRODUCTION

In the latest years, the production systems have largely evolved in order to improve the quality of the products, cut down on costs and reduce lead time. Thus, new Production Planning and Control techniques are strategically relevant to achieve these goals [1][2][3].

At the same time, simulation techniques have been more and more applied to solve a large number of manufacturing problems [4][10][13], for example: finding bottlenecks, validating plant layout, measuring labor and resources utilization, finding plant stocking policy, measuring production capacity and Production Planning and Control [7][8][9][11][12].

However, regarding to this last issue, simulation is not being used on a short-term basis. In a previous work, our research group proposed an approach called PPSS (Production Planning System based on Simulation) and evaluated its usage in finding a plant stocking policy. [5]

This work aims at evaluating the viability of deploying the PPSS approach to solve a short-term rescheduling problem by modifying the products input sequence. This viability can be analyzed based on the simulation time of the scenarios and on the effective impact of this rescheduling on the production time.

A rescheduling need may arise when any plant resource is out of order or has to be taken down for programmed maintenance. Besides, a rescheduling procedure may be necessary to achieve a certain product delivery date. For instance, if the current scheduling could not meet the delivery deadline of a product, a new schedule may meet it with a non-relevant delay in the total production time of the other products.

The scenarios were simulated over a plant being built at the Federal University of São Carlos, in the Artificial Intelligence and Automation Lab, plant which was proposed in a previous paper [6].

Finally, the paper can be outlined as follows: At first, the PPSS approach was revisited, then the modeled plant was presented and the PPSS technique is applied to this plant. This application led to some results which were shown and later analyzed. Based on this analysis the viability of the PPSS deployment was evaluated.

II. THE PPSS APPROACH

The Production Planning System based on Simulation (PPSS) verifies the performance of distinct actions or different possible arrangements using a simulation software and the plant status (inserted into a database).

Whenever necessary to make a decision, it’s possible to select a number of simulation models (previously designed to portray all important situations, either considering the current plant status or historical data), and verify the performance of each one.

The database will be built with information concerning the plant conditions (e.g. product stock, raw material, work in process, resources, etc.) supplied by the monitoring system and also with information related to the company strategies. All information must be constantly updated into the database, so that PPSS can provide the simulation software with the exact plant conditions at the decision-making moment.

This information can be gathered from a monitoring system based on a supervisory system, a PLC (Programmable Logic Controller) coupled to sensors, or from data collectors used by plant operators. The following picture shows an overview of the PPSS approach.
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Based on the inputs of the database, it’s necessary to pick up some scenarios and carry out the simulation. Then, the scenarios that achieved the specified goal are classified according to their performance and the best one can be chosen.

Picture 2 shows a flowchart describing the PPSS usage procedure.

The simulation model has taken into consideration not only plant-related issues but also production and resource-related ones. One-hour maintenance is performed every day on the AGVs, the machines are subjected to breakdowns according to input files, which also define production mix, batch sizes and products sequencing.

Also, it’s programmed a 30-minute setup for every machine, so that it can change its tools and make other adjustments to a type of product different from the last produced.

The factory manufactures three different kinds of products. Product “1” is the most simple one, demanding only three machines (1,3,5) and having a rough finish. Product “2” is the most sophisticated one, demanding four machines (2,3,4,6) and having a more polished finish. Product “3” is an intermediate one, with four alternatives production routes; the first two machines are either 1,2 (70%) or 3,4 (30%) and the finishing machine can be either 5 (35%) or 6 (65%).

Table 1 shows the production times for each product:

<table>
<thead>
<tr>
<th>Product</th>
<th>Mch 1</th>
<th>Mch 2</th>
<th>Mch 3</th>
<th>Mch 4</th>
<th>Mch 5</th>
<th>Mch 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product A</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Product B</td>
<td></td>
<td>2.1</td>
<td>0.9</td>
<td>1.6</td>
<td>1.85</td>
<td></td>
</tr>
<tr>
<td>Product C</td>
<td>1.1</td>
<td>1.4</td>
<td>1.3</td>
<td>2.1</td>
<td>1.9</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Table 1: Production Times (min)
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Petri Nets were used to model the plant and the production processes. The former can be found on [6] and the latter is shown below:

![Product A Petri Net](image1)

![Product B Petri Net](image2)

![Product C Petri Net](image3)

Picture 4: Petri Nets of the Production processes

A production mix of 45%, 30% and 25% was adopted for products “1”, “2” and “3”, respectively. This mix is expected to represent the current market demand.

Another preliminary study was carried out, so that a fitting batch size could be found. The time/product rate was analyzed and once that batch sizes bigger than 100 had a good performance, a 1000-product batch size was chosen. However, more batch sizes could have been simulated while analyzing different products input sequencing.

This plant layout is close to the one that is being currently built in the Artificial Intelligence and Automation Lab., at the Federal University of São Carlos.

IV. APPLYING THE PPSS TECHNIQUE

The previously specified plant was modelled using the Automod software from Autosimulations Inc. Picture 5 displays a snapshot of the software model.

![Snapshot of the software model](image4)

Besides developing the graphical representation and the production logic, some features were added to the model. It is capable of dynamically reading tabular text input files, which specify the batch size, total production, production mix, machines breakdown/maintenance and product input sequencing. Furthermore, it can generate customized reports that can be read by electronic worksheet programs and automatically update pre-built graphics.

A HTML shell was built in order to make easier to the operator the procedure of entering input data and analyzing the simulation results.

Once that all needed input data is defined out of the simulation environment (using simple text tables), no knowledge about the simulation software programming language or about its environment is demanded.

Another facility is that all the simulation scenarios are evaluated within only one simulation run, saving a lot of time in the results generation.

V. OBTAINED RESULTS

Below, machines breakdown and programmed maintenance were simulated, so that a products sequencing reprogramming could be performed when these events took place. That makes the plant capable of achieving products delivery deadlines with maximum productivity.

Six different plant conditions were analyzed, accounting for six different simulation scenarios. In the first one, the plant was fully operational with no machines out of order. In the second one, machine #2 was taken down in the 2nd day for twelve hours. Following the same idea other machines were taken down at different points of time, as shown in the following table:

<table>
<thead>
<tr>
<th>Rehearsal</th>
<th>Machine</th>
<th>Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2nd</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>11th</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>5th</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>9th</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>7th</td>
</tr>
</tbody>
</table>

*The machines were always taken down for twelve hours

Table 2: Simulated breakdowns

As the main goal of our project was to evaluate the viability of the PPSS deployment, the total simulation times for each rehearsal was measured and shown in table 3. The simulations were carried out (with no graphic animations) on two different PC desktop computers: one
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with a 300MHz clock and the other with a 1GHz clock, both with 256 MB RAM memories. Based on this automatically generated graphic, decisions can be made in order to reschedule the production in an ad-hoc manner.

Table 3: Total simulation time (min)

<table>
<thead>
<tr>
<th>Rehearsal</th>
<th>PC 300MHz</th>
<th>PC 1GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4:20:00</td>
<td>1:39:40</td>
</tr>
<tr>
<td>2</td>
<td>4:20:05</td>
<td>1:42:65</td>
</tr>
<tr>
<td>3</td>
<td>4:20:92</td>
<td>1:43:49</td>
</tr>
<tr>
<td>4</td>
<td>4:22:36</td>
<td>1:57:84</td>
</tr>
<tr>
<td>5</td>
<td>4:22:64</td>
<td>2:00:12</td>
</tr>
<tr>
<td>6</td>
<td>4:21:85</td>
<td>1:44:93</td>
</tr>
</tbody>
</table>

V. ANALYSIS OF THE PPSS-GENERATED SOLUTION

Analyzing the measured times it can be concluded that the PPSS deployment is not only viable but desirable, once that few minutes of simulation can provide results to determine whether a new sequencing is efficient and how efficient it is.

For instance, considering the 3rd rehearsal, when machine #2 was out of order in the 11th day for 12 hours, about four minutes of simulation (in a minimal hardware configuration) represented a 16-hour time reduction.

The following graphic shows all the results achieved in this rehearsal:

Picture 6: Results Comparisons
The PPSS could also be applied when a delivery deadline could not be reached because of an occurrence in the plant. The technique can help finding a trade-off between minimizing a specific product time and the total production time.

For example, in the 6th trial run, when the machine #3 was taken down in the 7th day for 12 hours, the difference between the best (1-2-3) and the worst (2-3-1) product sequencing is about 2 days, when concerning the product 1. The “1-2-3” sequencing is the most advisable one for the product 1, despite not being the most efficient regarding to total production.

The graphics below demonstrate these differences, being Picture 8 for product 1 and Picture 9 for the total production.

Also, further analysis can be drawn from picture 6. Some of the scenarios had a very close performance and could have been rejected during the simulation phase, saving even more simulation time and generating faster results.

VII. CONCLUSIONS

This paper aimed at evaluating the viability of the previously proposed PPSS approach when solving short-term production rescheduling problems. It was achieved by comparing the simulation times to the effective gain in the production.

First, the PPSS approach was revisited, outlining its main ideas and features. The usage of a simulation software and of the plant status data allows for an evaluation of distinct actions when the plant faces unforeseen occurrences.

Then the modeled plant was presented: its layout, products, batch size, production mix and the production time spent on each machine.

Following, the PPSS technique was applied to the plant presented. This application evaluated the input conditions, carried out the simulation run and showed the results, which were later analyzed.

This analysis came to justify the PPSS deployment, once that few minutes of simulation provide a trustworthy support for rescheduling decisions. In the case study presented, four minutes of simulation represented a 16-hour saving in the total production time.

Further research is being done in order to improve the technique. One example is a Fuzzy-Logic Expert System that is being developed to filter irrelevant input conditions, enhancing the performance of the approach by generating faster results.
VIII. BIBLIOGRAPHY


