Production Planning and Setup Time Optimization: An Industrial Case Study

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Abstract. Production activity control approaches, methods, and mechanisms have been widely applied over the last decades, and continue to be of utmost importance nowadays, within the context of the currently fast-growing Industry 4.0 era. In this paper, a Simio-based simulation model is proposed and its application in a printing factory is illustrated. The main aim of this work consists of providing general production planning improvements in the considered factory, with a special focus on the reduction of setup time. The proposed model is based on several distinct production activity control mechanisms, for instance, the CONWIP and the Routing Group mechanisms from Simio, which did enable to reach good improvements regarding a set of performance measures considered, including machines' setup time reduction, along with the maximization of the percentage of products delivered on time. Future work is also planned to be carried out to improve other kinds of performance measures, and by using other types of production activity control mechanisms, to be further applied in other industrial companies and sectors.

Keywords: Production planning and control · Optimization · Simulation · Scheduling · Setup

1 Introduction

Production planning and control (PPC) plays a crucial role in Companies [1], and one of its utmost concerns falls within optimization problems [2, 3].

An efficient PPC system enables information to be obtained and also efficiently manages material flows, the efficient use of people and equipment, coordination between the organization's internal activities with those of its suppliers, and also communication with its customers, according to market needs [1, 4, 5].

In short, a PPC system provides managers with support for decision making and operations management.

In this paper, a simulation model for production planning and setup optimization is presented, and its application to a printing company is further illustrated through a case study.

The application of the proposed simulation model in the printing company intends to enable a critical analysis to validate a new productive method for the company.

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To obtain a viable solution for the company, different Production Activity Control (PAC) methods were used to test which one could bring more income to the company. Two working days were considered and simulated. Also, their modes of production (according to the production control mechanisms) were changed to obtain results. According to the analysis of the results obtained, the CONWIP mechanism enabled to reach a higher performance compared to the Routing Group and Real Cases approaches in the company. Within the CONWIP mechanism, the “Largest Value First” showed superiority over the “Short Value First” and “First In First Out” dispatching rules, by enabling to obtain more products, with the same high-quality standards in a shorter period. According to the results obtained, the application of this new procedure in the Company can help to increase and improve production, as it aims to reduce costs in a given planned time horizon and without using any additional competitive advantages, for instance, regarding quality requisites.

This paper is organized as follows. Section 2 presents some general insights about production activity control, to briefly describe the main PAC approaches and mechanisms used in this work. Section 3 describes the industrial case study approached, and the proposed Simio-based simulation model developed. Section 4 refers to the analysis of the main results obtained. Finally, in Sect. 5, the main conclusions are outlined, along with some future work directions.

2 Literature Review

Production Activity Control focuses on several distinct management functions, and one of its main and also more studied ones is production scheduling [6]. Moreover, it is also generally noticeable that PAC, for instance, its production scheduling function shows a tendency, over the last decades, to be approached as a combinatorial problem to be solved by using exact and heuristic mathematical techniques [1, 2, 4, 6]. Although, and also with an increasing tendency, PAC, and more specifically production scheduling, are being studied through alternative approaches, including a variety of approximation algorithms and techniques [3, 7], the simulation technique [8–10] is gaining considerable visibility and affirmation, and experiencing a particular increase in the current Industry 4.0 context.

2.1 Production Activity Control Approaches and Mechanisms

A wide range of PAC approaches and mechanisms exists, based on quite different production paradigms and aiming at different objectives, through the evaluation of a varying set of performance measures. Some of the very well-known PAC mechanisms are the following:

Toyota Kanban System (TKS)
The Toyota Kanban System (TKS) is a PAC mechanism based on pull production and aiming to eliminate waste [11]. TKS’s premise is that the material will not be produced or moved until there is something or someone able to notify that need. For this reason, a Kanban system is used. A Kanban system is a subsystem of TKS and enables to control

the waiting levels in a production system. When a queue reaches its default maximum level, there is a need to launch an order to stop the production.

CONstant Work-In-Process (CONWIP)
The CONWIP control system was introduced in 1990 as an attempt to introduce a more flexible pull system than TKS [12]. In a pull system, production is based on actual demand. Therefore, production just occurs if there is a request for a product by the end customer - make-to-order production. This pull variant is known for its ease of implementation.

CONWIP can be applied in diverse production environments and, as a rule, is based on a card system that is linked to a particular job, being used so that no job can enter the system without the associated production authorization card [13].

3 Research Methodology

The basis of any scientific and engineering approach is modelling. Operational research models consist, according to [14], in a mathematical formulation that seeks to portray the real situation as well as possible, either in order to make better decisions or even just to better understand it [14, 15]. The same approach is addressed by simulation models, which were used in this work to represent the real contexts into computational software in order to generate different real scenarios to make better decisions. The simulation technique is also capable of modelling the real context uncertainty which provides a high degree of confidence when making a decision.

Like any model, a simulation model implicitly incorporates decision variables, parameters, and constraints. The objective function may or may not be modelled in the main model. This allows a much higher level of flexibility when analysing the system behaviour.

By crossing simulation and mathematical models, it is possible to obtain the optimal solution (mathematical models) and then test it with simulation to anticipate the behaviour of the system. As simulation models are capable of modelling system uncertainty (and usually the mathematical models cannot), the iterative application of both models usually leads to a confident feasible solution.

This chapter describes analyses and test changes to the production system of the company's printing section. These changes focus on the application of several rules for production activity control. The main objectives are to minimize the total production time and reduce delayed deliveries.

Therefore, a SIMIO software-based model [16] was developed (Fig. 1) to trustworthily represent the printing section of the company. Several production activity control mechanisms were implemented in order to test different scenarios and identify a more efficient method for the company.

This model was developed in simulation software, namely, SIMIO™. Figure 2 illustrates the model that represents the printing section. This model represents the conceptual modelling of the printing section. Each workstation (KBA_1, KBA_2, KBA_3, KBA_4) represents a different printing machine.

In this model, the entities that flow in the simulation model are the production orders. These orders were imported directly from an Excel file, which contains all relevant information. A total of 64 product families were considered for this model. When a production order arrives at the workstation, 2 tasks are performed: the preparation (setup time, if needed) and the processing time. In this sense, all the setup and processing times were defined for all product families.

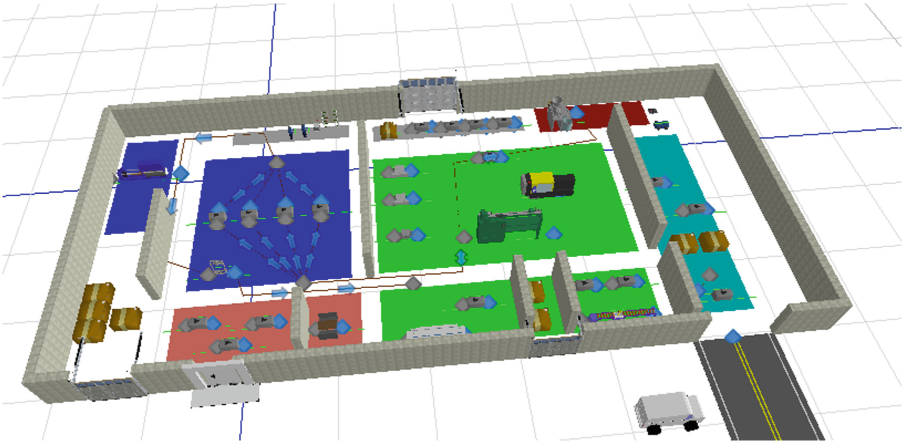

Fig. 1. Company layout representation (In SIMIO^{TM}).

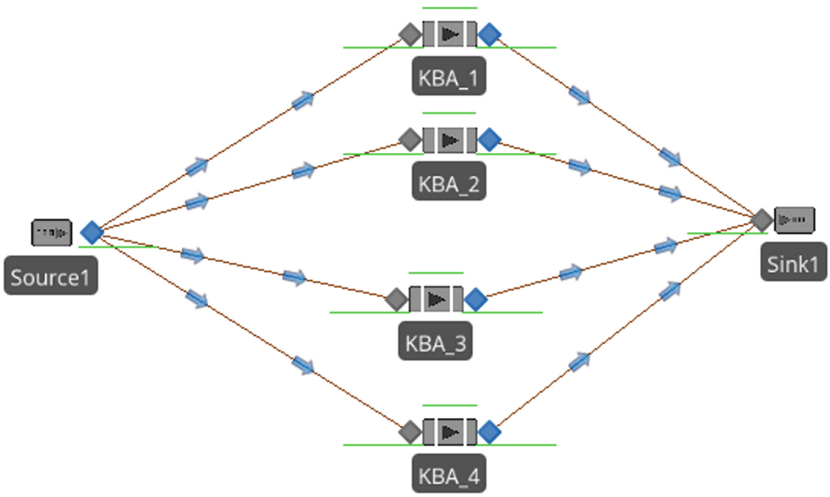

Fig. 2. Norprint production environment modelled on SIMIO^{TM} software.

To add additional and needed modelling logic to the SIMIO simulation model, several processes were created in order to compute the key performance indicators needed to assess system behaviour (for example, total production time, and a number of products delivered on time).

The implemented production control mechanisms were defined for different control stages of the production run. At the scheduling stage, two approaches were modelled, the FIFO and CONWIP approaches. At the sequencing stage, 4 methods were implemented: FIFO (the first order arriving at the workstation is the first order processed), the highest value of processing time (in Simio modelling the LVF – largest value first – is used to model this behaviour), the smallest value of production time (in Simio modelling the LVF – largest value first – is used to model this behaviour), and the Routing Group (a proprietary mechanism from Simio to allocate entities to workstations).

Along with the 4 printing machines production layout, a secondary layout was developed to test a context in which the printing section of the company would have 3 printing machines (instead of 4). This scenario aims to assess the feasibility of the 3 machines production layout, as during the project the possibility of selling one of the printing machines was revealed.

For all the alternative scenarios tested, the key performance indicators assessed were the time in the system and the percentage of product deliveries made on time.

4 Results

After analysing and validating the simulation model, two different scenarios were simulated. All tests were simulated applying 100 replications for each run, which confers statistical meaning to the results, guaranteeing a confidence interval level greater than 95%. The scenarios represent real case studies that the printing section had to tackle in two different days, such as:

- Real Case 1 – April 3 and 4, 2018;
- Real Case 2 – May 24 and 25, 2018.

4.1 Real Case 1

All the relevant information about the production process regarding the real case 1 is presented in Table 1.

The printing section deals with these orders and achieved a percentage of products delivered on time of around 35%. A simulation model representing the production control mechanisms of the real case scenario was used to validate the model. After running the simulation model, the results obtained were a percentage of 38,8% of products delivered on time and a total production time of 18,5 h. These values corroborate the simulation model's validity.

Thus, the next steps involve the implementation of different production control mechanisms to seek better solutions for the printing section.

Table 1. Real case 1 data (time in hours).

Order	Order ID	Family	Release date	Setup time	Production time	Total time	Family class
Obras Pioneiras	1	Part20	0	0,87	6,41	7,27	4
Everlux	2	Part38	0	0,28	7,41	7,70	6
Miguel D'atte	3	Part35	0	0,83	7,59	8,43	3
A Nona Vítima	4	Part1	0	0,25	6,70	6,95	1
O Livro das Decisões	5	Part17	0	0,25	6,41	6,66	1
Catálogo Galvão	6	Part56	0	0,87	7,29	8,15	8
Golden Generation	7	Part48	0	0,87	23,76	24,62	8
Belmiro dos Santos	8	Part23	0	0,83	6,48	7,31	7
Sinalux	9	Part54	0	0,28	6,95	7,24	6
Conselhos para ler	10	Part52	0	0,28	7,76	8,04	6

Routing Group

The Routing Group method considers the state of the queue of a workstation and also its remaining production capacity to allocate orders to workstations. This means that for the real case studies, by applying the Routing Group mechanism, each time a product is available to start production, the model compares all queues and remaining production capacity of all workstations and allocate product production to the workstation with more availability. This mechanism was implemented for the 4 printing machines layout and the 3 printing machines layout. For each scenario, the ranking rule for the products (meaning, the rule to define priority to start processing) was defined by the production time of each product and by the FIFO rule, which means 3 different scenarios for each layout applying the routing group mechanism. The results of the simulation are presented in Table 2.

As expected, in terms of total time in production, the scenarios with 4 printing machines' performance were better than in the scenarios with 3 printing machines. However, in terms of the percentage of products delivered on time, not all scenarios with 4 printing machines perform better than the scenarios with 3 printing machines. The scenario with 3 machines and the highest production time performs better than the scenario with 4 machines and the smallest production time regarding the percentage of products delivered on time. The scenario that performs better is the one with 4 machines and the highest production time with a percentage of products delivered on time of 56%. It means that giving priority to orders with high production times will lead to better production performance. Globally, every scenario performed better (or at least the same) than the real printing section production in real case 1.

Table 2. Results of the Routing Group mechanism for real case 1.

Scenario		Results	
Layout	Ranking rule	Total time in production	% of on-time deliveries
4 machines	FIFO	17.31	48.8
4 machines	Highest production time	17.24	56.0
4 machines	Smallest production time	17.31	44.8
3 machines	FIFO	22.27	35.9
3 machines	Highest production time	23.05	45.5
3 machines	Smallest production time	18.13	35.9

CONWIP

In this section, the same scenarios are simulated by changing the production control mechanism to CONWIP. The results of the simulation are presented in Table 3.

By applying the CONWIP mechanism it is possible to observe that the differences between scenarios of 3 and 4 machines are not as noticeable as with the application of the routing group method. There is a scenario with 4 machines that performed worse than all the scenarios with 3 machines. Regarding the percentage of products delivered on time, all the scenarios with 4 machines performed better than the scenarios with 3 machines. Again, the scenario with better performance is the one with 4 printing machines and with the ranking rule as the highest production time. This scenario achieves 56, 02% in terms of the percentage of products delivered on time.

Table 3. Results of the CONWIP mechanism for real case 1.

Scenario		Results	
Layout	Ranking rule	Total time in production	% of on-time deliveries
4 machines	FIFO	17.18	44.8
4 machines	Highest production time	17.17	56.0
4 machines	Smallest production time	21.33	42.2
3 machines	FIFO	18.30	35.9
3 machines	Highest production time	17.47	38.7
3 machines	Smallest production time	18.05	35.9

Comparing both mechanisms (routing group and CONWIP), it is not possible to unequivocally highlight the best mechanism. It is possible to verify a slightly better performance of the CONWIP mechanism in terms of reducing the total time in production, and it is possible to verify a slightly better performance of the routing group mechanism in terms of the percentage of products delivered on time.

4.2 Real Case 2

This case study is important to prove the robustness of the simulation model, as the typology of orders is different from the ones simulated in real case 1. All the relevant information about the production process regarding the real case 1 is presented in Table 4. The real results that the printing section obtained on the 24th and 25th of May, regarding the percentage of products delivered on time, was around 35%.

Next, the same control mechanisms are applied to seek a better performance for the printing section.

Table 4. Real case data 2 (time in hours).

Order	Order ID	Family	Setup time	Production time	Total time	Family class
Galeria Militar	1	Part40	0,87	7,75	8,61	8
Banda Desenhada	2	Part29	0,25	22,46	22,71	5
LaForcade	3	Part23	0,83	6,48	7,31	7
Fotogaleria Estação Coimbra	4	Part48	0,87	23,76	24,62	8
Atelier Digital	5	Part5	0,25	6,76	7,01	5
Na Massa do Sangue	6	Part17	0,25	6,41	6,66	1
A Garrafa Mágica	7	Part1	0,25	6,70	6,95	1
Material Escolar	8	Part29	0,25	22,46	22,71	5
Cerâmica	9	Part24	0,87	6,48	7,35	8
Jerusalém	10	Part34	0,28	7,32	7,60	2
Primeiro Tratado Pedagógico	11	Part33	0,25	7,30	7,55	1
O Ano da Morte de Ricardo Reis	12	Part9	0,25	22,71	22,96	1
Paula Rego	13	Part9	0,25	22,71	22,96	1

Routing Group

The same type of scenarios was simulated with the routing group control mechanism. The results obtained are presented in Table 5.

Table 5. Results of the Routing Group mechanism for real case 2.

Scenario		Results	
Layout	Ranking rule	Total time in production	% of on-time deliveries
4 machines	FIFO	27.89	39.0
4 machines	Highest production time	29.30	46.8
4 machines	Smallest production time	27.89	39.0
3 machines	FIFO	32.11	37.9
3 machines	Highest production time	37.22	58.1
3 machines	Smallest production time	29.30	32.5

As expected, generally, the scenarios with 4 printing machines perform better in terms of total time in production. In terms of the percentage of products delivered on time, the scenarios with 3 machines perform worse except for the scenario with 3 machines and the highest production time, which is the best scenario of all, with 58.1% of products delivered on time. Again, globally, regarding the percentage of products delivered on time, all scenarios performed better than the printing section real production except for the scenario with 3 machines and the smallest production time with 32.5% (worse than the 35% of the real case).

CONWIP

In this section, the same scenarios are simulated by changing the production control mechanism to CONWIP. The results of the simulation are presented in Table 6.

By applying the CONWIP mechanism it is possible to observe that, generally, in terms of total time in production, the scenarios with 4 machines perform better than the scenarios with 3 machines. Moreover, comparing to the routing group mechanism, the CONWIP mechanism performed better in all scenarios considering the total time in production. Regarding the percentage of products delivered on time, all scenarios with 3 and 4 machines performed worse with CONWIP than the respective scenarios with the routing group, except for the scenario with 4 machines and the highest production time that performs better and is the best scenario of all. This scenario achieves 68, 03% in terms of the percentage of products delivered on time, which represents almost the double amount of products delivered on time.

Table 6. Results of the CONWIP mechanism for real case 2.

Scenario		Results	
Layout	Ranking rule	Total time in production	% of on-time deliveries
4 machines	FIFO	24.67	37.6
4 machines	Highest production time	27.57	68.0
4 machines	Smallest production time	23.46	33.4
3 machines	FIFO	29.01	35.9
3 machines	Highest production time	35.02	45.8
3 machines	Smallest production time	27.50	29.5

Comparing both mechanisms (routing group and CONWIP), no mechanism stands out in terms of global performance. Nevertheless, the mechanism that presents more consistency in delivering the best scenario is the CONWIP. In both real case studies, the CONWIP mechanism presented the best scenario (in real case 1 tied with the routing group). Additionally, considering the clients' point of view, the most important indicator is the percentage of products delivered on time, which corroborates the selection of the CONWIP mechanism (merged with the highest production time ranking rule) as the best mechanism for the production control of the printing section.

5 Conclusion

Throughout the development of this project, it was possible to realize that the proposed simulation model for supporting production activity control at a printing company showed improvements compared to those used at the company. Therefore, the use of the proposed simulation model enables us to reach general benefits, not just in terms of improved production efficiency, but also and consequently, through an increased level of customer satisfaction. Through this project, it was possible to achieve better production performance, for instance, regarding total setup time reduction.

Two different real case studies were simulated in a total of 24 generated and analysed scenarios. All scenarios ran 100 replications, which confer statistical significance to the results (over 95% confidence). The routing group mechanism (property of Simio) and the CONWIP mechanism were simulated for both real case studies and, although no mechanism has stood out in terms of global performance, the CONWIP mechanism demonstrated more consistency in delivering better results. The best scenario, considering the percentage of products delivered on time (the most important performance indicator from the clients' point of view) was achieved by the application of the CONWIP mechanism with the highest production time as a ranking rule, achieving a percentage of 68.0%.

In the prospects, it is suggested to apply the developed Simio-based simulation model to other industrial environments and sectors, along with the implementation of sensitivity analysis of the model, in order to further test the effect of variations of any of the production activity control mechanisms and underling variables used. Additionally, and to make the model increasingly reliable, it would be interesting to introduce two more variants of the model, by integrating: a production failure/interruption factor of the machines; add work orders with urgent priority; and also, consider the percentage of utilization of the machines in the workspace.

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