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Towards a Scheduling Optimization Support Tool for a Perfume Manufacturing Process

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Abstract. The satisfaction of an increasingly personalized and unpredictable demand that certain companies are experiencing demand flexible production systems. The large number and complexity of the parameters to be taken into account most often require a scheduling support system to meet delivery times and optimize the use of resources. We present the industrial and research issues then a synthesis of the state of the art on the different types of scheduling problems. We chose a simulation approach for our scheduling tool. After defining the specifications of the scheduling tool and how the corresponding industrial data have been collected, the RFLP (Requirements, Functional, Logical and Physical) models of the perfume manufacturing case study on which the scheduling support will be based, are then presented.

Keywords: Scheduling · Simulation · Perfume manufacturing · Industry 4.0

1 Introduction

A large number of companies are experiencing an evolution of its market with the multiplication of their direct customers, an increasingly personalized and unpredictable demand. Indeed, even if most of distribution is done through wholesalers, the development of electronic commerce is becoming increasingly important and can no longer be neglected. Splitting the volume of orders and multiplying distribution points result in ever smaller batch sizes, frequent series changes and finally require a high degree of flexibility and adaptability of production systems.

The objective of the work presented in this article is to develop a scheduling tool to help companies face these increasingly personalized demands applied to a perfume manufacturing workshop.

The paper is organized as follows: industrial context and state of the art related to the research issue addressed and the approach selected are first presented; needs analysis regarding the data gathering and scheduling tool specifications are highlighted in Sect. 2; compliant modeling of the case study manufacturing workshop is described in Sect. 3 followed by the conclusion and the announcement of future work.

1.1 Industrial Context

The evolution of personalized customer's request, combined with continuous changes in product formats, requires a high degree of flexibility to increase the ability of production system to adapt to these changes. In parallel, the increasing introduction of information technologies into manufacturing processes, which appears to be the 4th industrial revolution (Industry 4.0), is reflected in the use of intelligent and connected production systems. Thus, the control of industrial automated production systems is evolving today by integrating embedded intelligence. This intelligence makes it possible to extract as much elaborate information as possible and to increase the reactivity of the control system. At the same time, the management of the production tool requires taking into account many parameters (product-process characteristics, supply, subcontracting, distribution, installation capacity, etc.) that complicate the decision-making process.

Besides, production lines are generally adapted to a product, so it is useful to take into account the interdependence of product and process data [1], to improve their design and thus product quality, and to allow a high degree of operational exploitation. Existing tools and approaches make it possible to model and simulate production lines at different scales for the control and management of production lines: process analysis in the context of the "digital factory" [2]; analysis of the behavior of mechatronic systems in production lines [3].

1.2 Research Issue

The improvement of flexibility can be achieved at the process control level (optimization of manufacturing processes and human resources scheduling …), but also in the implementation of the manufacturing system (choice of equipment and the definition of their relating architecture and configuration). In this paper, we focus on the first approach tackling the scheduling optimization issue.

1.3 State-of-the-Art and Proposal

Production scheduling is defined by S.C. Graves [4] as "*the allocation of available production resources over time to best meet certain criteria*". In a context of tasks or operations to be performed under time and resource constraints, a scheduling problem consists in giving which process occupies which machine and the times to start the tasks, in order to optimize a certain criterion.

Scheduling approaches depend on the of the scheduling problem typology they address. Different criteria can be consider to classify scheduling problems such as 1) Source of requirements, 2) Manufacturing process structure, 3) Parameters knowledge confidence and 4) The production system environment. When considering the first criteria, two kinds of situations can be distinguished: open shops for which requirements are based on the customers' needs and closed shops for which requirements are based on stock levels. Considering the structure of the manufacturing process, i.e. the number of stages and associated processors we can distinguish between processes with a unique stage and processes with several stages. The level of confidence in the knowledge of process parameters is another factor in the selection of a scheduling method. Indeed, manufacturing processes with constant and determinist parameters will be easier to schedule than dynamic and stochastic ones. Finally, the production system environment can be as static or dynamic. As a result, we can classify existing scheduling approaches according to these different points of view (see Table 1).

Table 1. Scheduling methods categories and related existing literature

	Point of view	Example of existing literature
Source of requirements	Open shop	[5]
	Closed shop	[6]
Manufacturing process structure	One stage/One processor	[7]
	Multistage flow/Job shop	[8]
Parameters knowledge confidence	Determinist	[9]
	Stochastic	[10]
Production system environment	Static	[11]
	Dynamic	[10]

Scheduling problems are generally NP-difficult [5, 12], so it is mainly methods of approached resolution that are developed for practical cases. The majority of published resolution models and techniques apply to simple, deterministic and static scheduling problems [10]. However, most of the real scheduling problems are stochastic (e.g. uncertain operating time) and dynamic (customer requests, equipment or operator unavailability, etc.) and depend on many parameters that are not always known. To that respect, we propose to use simulation to address our scheduling problems. Nevertheless, we must pay particular attention to its limitations highlighted by [10]. Simulation models do not always have a theoretical meaning, in our case, this point is not critical since the proposed model will only represent the necessary and sufficient view to address the scheduling problem, without attempting to represent the system in an exhaustive way. Additionally, the interpretation of the simulation results is limited because it depends on the scenarios tested (quantity, perimeter, hypothesis). Finally, as the value, accuracy and credibility of simulation results are largely dependent of the quality of the simulation models and then the judgment and skills of the programmer, we will particularly watch out on the model and scenario data adequacy regarding the simulation objective.

2 Scheduling Tool Specification Definition

The decision support tool to be developed has to optimize the manufacturing process based on a strategic production plan including dynamic change of the market behavior.

2.1 Functional Analysis

Performing the modeling of the manufacturing system that will be used as support to the scheduling tool, requires the knowledge of the relevant parameters, in order to adapt the model perimeter and refinement to the objective of the simulation. For that respect, we realized a processes mapping with a "Suppliers, Inputs, Processes, Outputs and Customers" (SIPOC) in order to identify the different process steps from the supplier (inputs) to the customer (outputs) and their operational parameters. The manufacturing process include different stages through which all production batches pass. Each stage consists of one or more workstations that can be different. Then the implementation of a scheduling tool that, for a set of batches over a given period, will define the order of completion and the assignment of batches to each workstation.

Then regarding the objective of the analysis (here scheduling optimization), the second step consists in selecting, among all the parameters identified, those that are relevant to the objective fixed. These relevant parameters will be those that have to be both collected for the selected industrial scenarios (strategic production plan) and provided in the system modeling to be developed.

Finally, the tool to be developed (see Fig. 1) will have to take into account the current situation of the production system (current production in progress and corresponding availability of production equipment and downstream systems), the current demand (manufacturing order with earliest starting date and latest ending date). Based on this information, the scheduling tool will have to provide an "optimal" scheduling according to one or more performance criteria: maximum completion time, average time to complete all of the jobs, cost, etc.

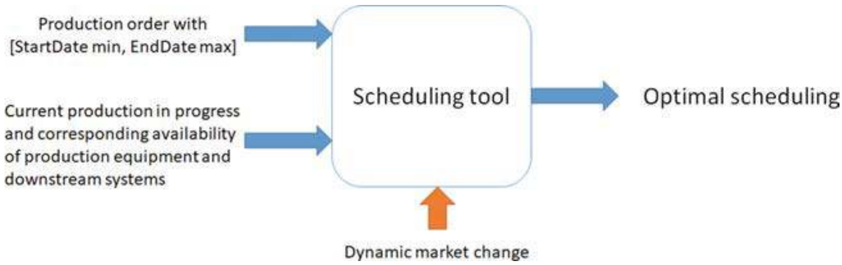

Fig. 1. Inputs and output data of the scheduling tool

2.2 Data Gathering

The simulation scenarios will be built on a strategic production plan and some assumptions based on production history, observed and future market trends. Consequently, our approach requires the collection of useful data to feed the modeling of the manufacturing system in order to ensure a reliable scheduling. To meet this need, we conducted questionnaires to the staff of the company. These questionnaires later made it possible to build a database to feed our model with real input data in order to have realistic simulations. The questionnaires were written from the specifications of the industrial company that is the subject of our case study and field observations of the perfume manufacturing process.

Indeed, the collection of information and documents is a key step in our approach. We conducted our questionnaires in the form of individual interviews with employees attached to the perfume juice manufacturing department and who have good experience in their positions. In parallel, we have identified company-specific documents that contain important data for our study.

Based on the SIPOC representation of the case study (Fig. 4), these interviews have made it possible to build a database with the following information: Production plan at X months: annual and monthly quantity (seasonality and integrating peaks of activities), reference number of products, prioritization of references, manufacturing process stages time, batch size, opening time of the workshop, human resources availability, parameters of consumption of the lines of conditioning, quality level.

3 System Modeling

3.1 Presentation of the Manufacturing Process

The process of the perfume manufacturing is generally accomplished by two main phases: the production of perfume juice and the packaging on line. Our research work focuses on the first process of perfume juice manufacturing as shown the Fig. 2.

Fig. 2. Perfume manufacturing process

This process begins with the maceration phase by mixing the alcohol and the perfume concentrate and then letting it macerate for a specific period of time according to the product specifications. Once the maceration of the mixture is done, the second phase consists in the ice-filtration by freezing and filtering the macerated perfume juice in order to eliminate impurities and residues of the juice concentrate after the mixture saturation. Finally, the process is completed by the third phase of storage. The stored perfume juice will be then conveyed to the second phase of production: packaging on line. Each process step needs to fulfill specific requirements (such as: availability of material and human resources, cleaning of tanks, etc.) and to satisfy input parameters of product.

3.2 Modeling Tool and Case Study Description

Two modeling tools have been chosen, in order to describe the case study: perfume manufacturing process.

The free Aris Express software [13] provides a static description of the process (activities, inputs/outputs, resources, product flows, location, equipment and consumables). The 3DEXPERIENCE Platform is a business experience platform that integrates a design framework named RFLP as unique data referential to support a Systems Engineering process with requirements (R), functions (F) and logical product definition (L) such as components including 0-1D models, physical product definition (P) including multidimensional models [14]. Even if this platform is mainly dedicated to products design, we have chosen it, since it provides an integrated modeling platform supporting functional analysis and dependency links traceability to facilitate verification process regarding the scheduling optimization objective. The perfume manufacturing process consists of 4 main activities: cleaning, maceration, freezing and filtration and storing. The cleaning process is shown Fig. 3 as an example.

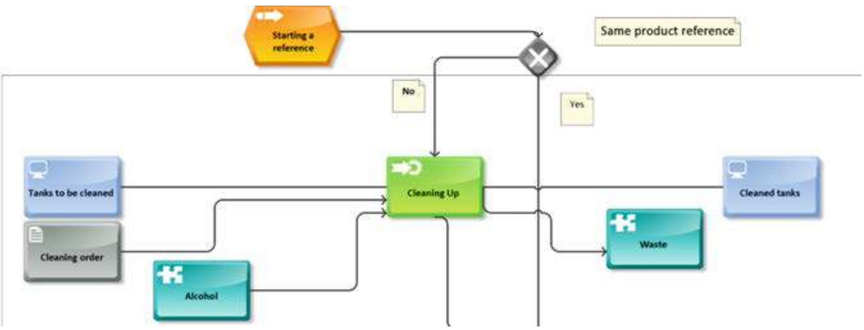

Fig. 3. Cleaning stage description

3.3 SIPOC Analysis

The relevant parameters for each activities to be taken into consideration for the simulation have been identified from the SIPOC view. An extract of the SIPOC of the perfume manufacturing process is given in Fig. 4.

Process	Supplier	INPUT	Resources	Parameters	OUTPUT	Requirements	Product features	Customer
Cleaning	Manufacturing service agent (hot water) Raw material supplier (Alcohol) Manufacturing Manager (Cleaning Order)	Hot water Alcohol Cleaning order	Manufacturing service agent Movable pump Hot water production unit	Quantities of alcohol and hot water according to the size of the tank Hot water temperature	Cleaned tank	Cleaning quality	Juice composition	Maceration Freezing Storing

Fig. 4. Extract of the case study SIPOC

An extract of relevant parameters and variables are presented in Table 2.

Table 2. Extract of relevant parameters and variables for the system modeling

Scope	Parameters	Variables
Product	Juice reference Juice volume Juice composition	
Infrastructure	Tanks number Tank volume	
	Tank stirring system Freezing/Filtration flow rate	
Process	Maceration time	Storing time
	Freezing/Filtration time	Human resource need
Scheduling	Production plan (delay)	Cleaning need
	Manufacturing orders	Storing need

3.4 Requirements

The requirements of the perfume manufacturing process (see Fig. 5) have been categorized in 4 types: the requirements related to (1) the organization notably to the human resources and business hours, to (2) the rules and regulations (Quality, Safety, Good Manufacturing Practice), to (3) the infrastructure (tanks and freezing/filtration equipment) and finally to (4) the product (composition, stirring, volume) and the scheduling process (cleaning, filter change and storing activities).

Fig. 5. Case study requirements

3.5 Functional Architecture

The functional architecture of the perfume manufacturing process, composed of three main functions (Maceration including dosing, cleaning and quality sampling, Freezing/filtration and Storing) is presented in Fig. 6 and Fig. 7.

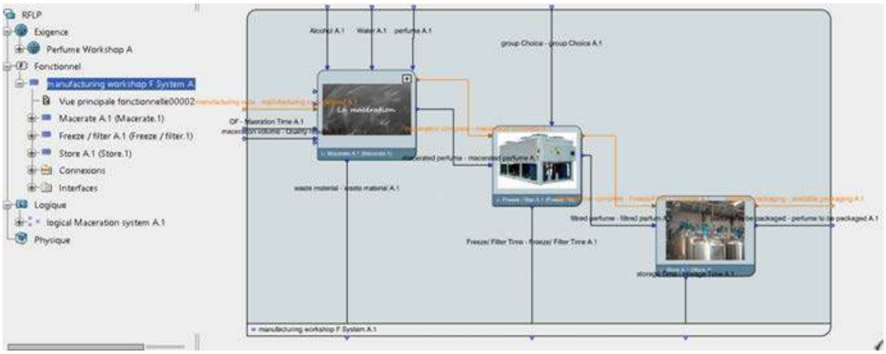

Fig. 6. Case study functional architecture

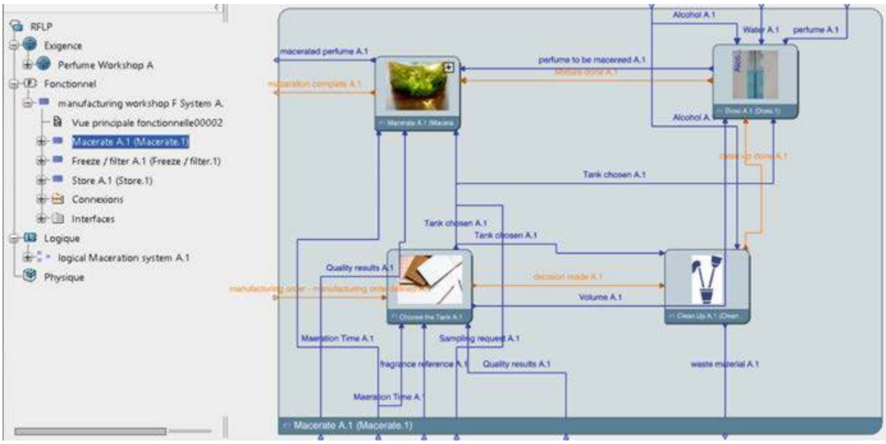

Fig. 7. Maceration stage detailed functional architecture.

The functional view provides the external inputs/outputs (Manufacturing Order features, juice availability for packaging, etc.), the main flows exchanges between the different activities (in blue) but also the sequence/temporal logic between these activities (in orange).

3.6 Logical Architecture

The logical architecture integrates the system behavior to be simulated to meet the scheduling optimization objective. An example is given in Fig. 8 for the dosing activity, this model provides the process time, by measuring the delay between the start of the dosing (tank volume becomes different from zero, and the end when the tank volume equal the juice volume desired).

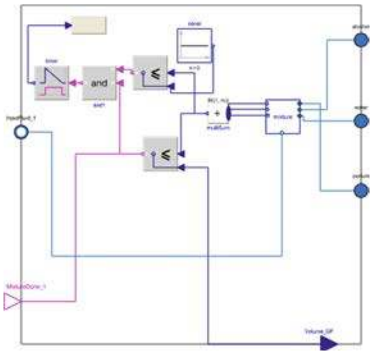

Fig. 8. Dosing activity logical modeling

3.7 Physical Architecture

The physical architecture represent the 3D model of the infrastructure and of the products to dynamically visualize the online process, it will be particularly interesting when we will optimize the manufacturing process through its equipment architecture reconfiguration or modification. For the scheduling optimization, we did not need this representation of the system.

4 Conclusion and Future Work

This research work focuses on the development of a scheduling support tool. The case study was provided by one of our industrial partners in the cosmetics sector. The first phase of the work was to define the industrial problem and to realize a literature review. The results of this first phase (industrial problems definition and literature review) led us to a simulation approach for the implementation of the scheduling aid tool. Indeed, our scheduling problem like most real scheduling problems are complex, stochastic and dynamic problems. After the specification of the support tool to put in place, we realized the RFLP model of the production system on which the scheduling support tool will be based. Future work will address the development and implementation of the scheduling support tool.

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