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Research Paper

Production Optimization on the Flow Shop Scheduling Problem: A Simulation Study

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Abstract

In today's manufacturing processes, production optimization is very important to increase the competitive edge, so production managers are hardly trying to increase their production output (without increasing resources) by using different manufacturing processes and different fields of industrial engineering. These methods are used in productivity and decrease the cost of goods sold, which managers favor in all companies. This paper investigated the optimization problem in a flow shop production line with the probable time and the other constraints such as limited equipment, manufacturing process limit, by using scheduling techniques and creating a learning system by simulating. We use a simulation-based optimization approach that combines simulation and exact methods to solve the Flow Shop Scheduling problem. simulation software used to reduce the constraints and exact model used for optimizing answers that can be efficient and effective. Implementing this model with all its probable components in a high-tech pharmaceutical company with many different products increases utilization and largely to those outputs have increased by 12%.

Keywords

Production, Simulation, Optimization, Bottlenecks, Queuing Systems

Abbreviation

TOC: Theory of Constraint
WIP: Work in process
MPS: Master Production Schedule
DES: Discrete event simulation
Past: A doughy substance that turns into tablets
SIMAN: The programming language which is using for designing Arena software

1. Introduction

As the competitive market in the world grows, the optimal use of resources plays an important role in the factory's development. Different methods, such as exact algorithms, heuristics, meta-heuristics methods, simulation, etc. are used [1]. One of the best techniques is conducting research operations, using methods such as mathematical modeling, for analyzing complex problems, which always enable the executives to make more appropriate decisions and create an efficient and productive system. In short, operations research can be considered the use of mathematical modeling to solve real problems to represent the best possible decision [2]. The other method that can help increase the use of resources is line balancing, which increases the utilization of resources and is one of the most important achievements in planning production systems [3]. The other method is conducting research operations; it is a technique to use analytical methods developed to help make better decisions. Thus, given that the subject of our research is the specific production of drugs and probable system variables, we must combine the linear optimization technique in an environment that can analyze the probable data and provide the mathematical model as input is required. Also, the assembly line balance technique should be used to improve the inputs for reducing the optimization time, because the optimization time is very important due to the constant changes in the sales orders.

In this paper, in the target factory, the production must be in batch form and special equipment for drug production is used; according to international instructions, the next batch should not enter the line until each batch has left a certain part of the production line, therefore, balancing the production line and optimal use of resources is the most important factor in improving production. Due to the specificity of this industry, there is little research in the relevant literature on the optimization of this industry, which led us to address it in this article. Firstly, by gathering data in production lines and the data in the databases, a simulation model was created and secondly, MPS was transferred to the simulation software through an intermediary file for starting model. Then, by solving the FSSP (Flow Shop Scheduling Problem) model by exact method, optimization occurred. This essay is organized as follows: First, you read the literature review, the second part is the problem statement and number three is the methodology and discussion and the conclusion is the final part.

2. Literature reviews

Simulation method applied for different sequence patterns in flow shop scheduling. The other researches that have been done in pharmaceutical industries reported that for quick responses to changing market trends, having synchronized inventory management and supply chain debottlenecking is highly important. The events happening in the supply chain were needed for understanding the system. Estimate capacity using scheduling tools was used for just-in-time production, low work-in-progress (WIP), and low product inventories [4]. One excellent piece of research introduced a discrete event simulation for achieving a flexible scheduling review. This method measured resource utilization, identifying bottlenecks, product output. The other research described the use of these tools for the development of bioprocess, design, and manufacturing [5]. Other researchers published hybrid modeling using simulation-based optimization for solving NP-Hard problems, viz., and job shop scheduling [6]. The other model then showed changes in product sequence and allocating resources as needed [7]. Different methods in maintenance strategies were checked as follows: Corrective Maintenance, Preventive Maintenance, Opportunistic Maintenance, and Condition-Based Maintenance. The research results suggest optimization in strategies of maintenance that leads to near-optimal solutions [8]. Simulation helped to calculate the number of possible factors in the transportation system and also a non-dominated sorting genetic algorithm (NSGA-II) was used in optimizing layout for satisfying the objective functions [9]. The scheduling approach suggested by the authors [10] used different arrival patterns for scheduling the products in one group. The simulators such as discrete event simulators, or finite capacity scheduling tools can be used in both the main and detailed design of integrated biopharmaceutical processes. At first, for probable changes like due date or order cancellation GRASP/G&T algorithm was used to solve FJSP and DFJSP with uncertain events. In DFJSP, factors that influence real manufacturing systems such as setup times, machine capacity constraints, ORR mechanism, order acceptance/rejection decisions were considered. Monte Carlo simulation model was used for analyzing and optimizing the time interval between periodic inspections in cold standby systems for lowest cost development. Both TTF (Times to failure) and total cost per cycle were considered by modeling and simulating and making a sensitivity analysis to verify the effects of the parameters in the best time interval between inspections [11, 12]. For managing and scheduling, new product development including probable activities, timing, and resources, one important characteristic of using simulation was that eliminating the need for a mathematical algorithm and only implementing a conceptual model was required. The simulation takes into account all the complications and random parameters. In the other research by using Monte Carlo simulation, Flow Shop Scheduling Problem with stochastic processing times was solved [13]. Durable scheduling for a flexible job-shop problem with random machine breakdowns had been investigated by the researchers [14, 15] for trading between the cost of logistics and customers' experience used simulation-based optimization. When we work on production dynamics, optimizing various maintenance strategies with their parameters is so important and, in this essay, Stochastic Discrete Event Simulation models were developed and connected to a multi-objective optimization engine used DEA for choosing the best scenario between simulation outputs with PM variables [16].

3. Problem statement

In designing the production line, if all resources are 100% utilized, there is the best situation in terms of production costs and, consequently, competitiveness is guaranteed, but factors such as raw material supply, equipment life, learning curve, social factors affecting manpower the time of the operation is influenced negatively.

of operations to change, the breakdowns become probable and sometimes fuzzy, and as we know, if there is a probable parameter in a system, the whole system becomes probable, so it is impossible to balance the production line 100%. Therefore, this study was conducted to optimize the use of resources in a pharmacy line with a specific

production limit. Given that in each part of this production line, each production batch must be finished and then the next batch is started, the optimal use of resources plays a crucial role in optimization (Figure. 1), so we use linear programming and a learning system with simulation in which probable variables can be entered.

Table1. Overview for literature

Row	Author	Scheduling Problem			Probable state		Maintenance strategy			No. of Product type		Backward/forward process		Research method				Objective function		
		Job shop	**Flow shop**	**Network**	**Stochastic**	**Deterministic**	**No maintenance**	**CM***	**PM****	**Mono product**	**Multi-product**	**Rework**	**No back ward**	**Simulation base optimization**	**Fuzzy**	**Heuristic**	**System dynamic**	**Makespan**	**WIP**	**Cost**
1	Petrides, et al. [5]		√		√			√			√		√	√					√	
2	Kaylani and Atieh [7]	√				√	√				√		√	√				√		
3	Alrabghi, Tiwari et al. [8]		√		√			√	√		√		√	√				√		
4	Sadegh et al. [12]			√		√	√			√			√	√						√
5	Mendes and Lorenzoni [11]		√		√			√			√		√	√				√		√
6	Sajadi, et al. [14]	√			√			√			√		√	√				√		
7	Aiassi, et al. [15]			√	√		√				√		√	√						√
8	Davari, et al. [16]		√		√				√		√		√		√			√		

4. Methodology

In the production process there is high complexity involving many probable variables, so a simulation model is developed and used for simulating the behavior of the production under any given schedule. The model had two methods:

1-The computer simulation model

-Arena software for obtaining distribution functions, modeling, etc.

-An Excel file, which will interact with the simulation model and is used for reading/writing data

2- An exact model for solving FSSP

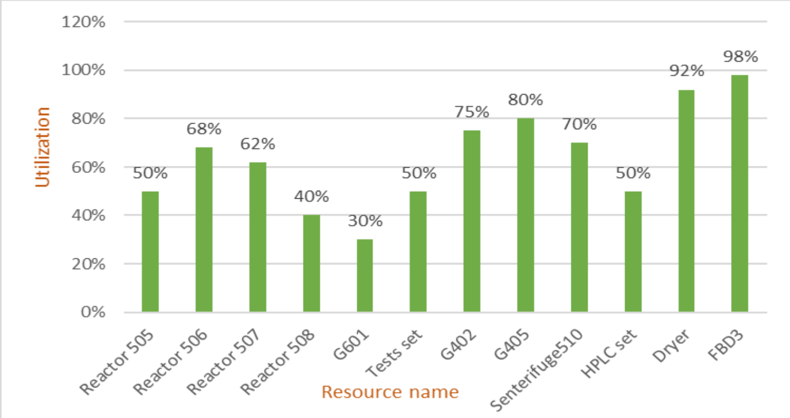

Figure 1. Utilization of resources in a period

4.1 Simulation

Computer simulation, in particular, has improved the accuracy of our understanding and decisions concerning complex systems and their processes. A simulation is a tool in which we can build a model with static, continuous, discrete, and random parameters. Arena software is one of the most effective simulation tools based on the SIMAN simulation language and uses graphical and visual modeling to facilitate the creation of a variety of models [17]. So, we make a simulation model in Arena and enter all of their parameters (probable and exact then after verification and validation run the model; indicators (Average number waiting and Average time waiting) can show us which operation must be utilization balanced and, in this case, we can make solvable exact model.

4.2 Solving FSSP

We know that FSS is an NP-Hard problem and can't be solved by exact methods. On the other hand, for optimization, we must solve a mathematical model like the following model, so after running the simulation model, according to the indicators, we optimize only operations that need to be optimized with specials MPS sequencing and in this case number of constraints considerably reduced.

4.3 Mathematic model

The mathematical model that must be solved to maximum output is as follow:

Notations used for model:

1- q: Number of products,
2- o: Schedule horizon
3- i: Indices for batches,
4- j: Indices for months,
5- t: Indices for stations,
6- s: Number of stations,
7- e: Number of used reactors,
8- N: Number of available reactors
9- R_t: Reactors used in station t
10- X_{ij}: Number of batches per month and per product

11- WIP: Amount of WIP in the production line
12- C: Capacity of each station
13- N: Maximum number of main resources
14- ST_i: Standard time of product i

This model should be solved to optimize the production output is:

$$\text{Max} \sum_{j=1}^{o} \sum_{i=1}^{q} X_{ij} \quad (1)$$

St:

$$\sum_{t=1}^{s} \sum_{i=1}^{q} X_{ij} \leq 2 \quad (2)$$

$$\sum_{t=1}^{s} R_t \leq N \quad (3)$$

$$\sum_{i=1}^{q} X_{ij} * STi \leq C_1 \qquad \text{for } j \in [1, 2\ldots o] \quad (4)$$

$$X_{ij} \geq 0 \quad (5)$$

As you see in the above model with a large number of products and operations there is plenty of constraints should be met. But when we use simulation, for example, if we want to optimize WIP, only we use constraint number 2. In our case study, we want to use our resources in an optimum case so with constraint number 4 we can solve our problem.

5. Case study

A case study has been conducted in a pharmaceutical factory whose production process is shown in Figure 2. Firstly, the raw materials enter the warehouse with the approval of the laboratory (1,2); then, in the first stage, the materials are charged in special reactors, and combined (3). After the special test (4,5) they enter the second stage; in this stage, they are placed under several press and filter models and enter another reactor (6,7). At this stage, Past is combined with the other compounds, which were previously prepared in another reactor, and they are filtered and combined again (8). The solution is ready for the IR test (9,10). Immediately after passing the test, the Past enters the purification and the centrifugation stage (11), and in this stage, after several repetitions and reaching the specified purity (12), it enters the next test stage (13,14). The dryer is the last step of the sieving operation, and after the final inspection of the product, the shipping units are transferred to the product warehouse (15,16).

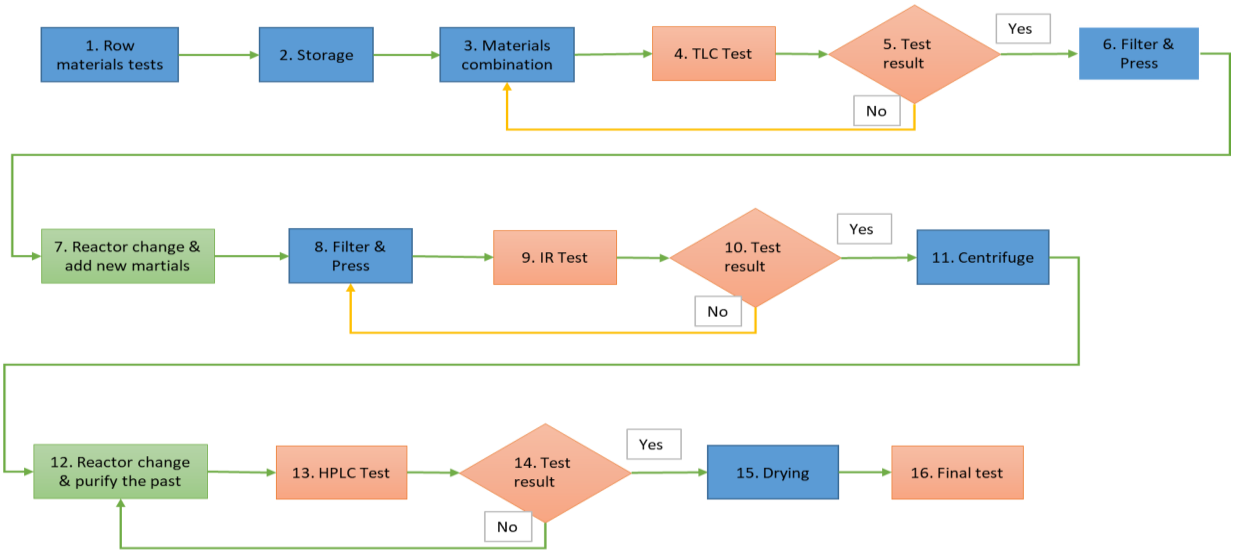

Figure 2. Routing for one of the products

5.1 Simulation Model

Arena-Rockwell software v. 14 is used to create a discrete event simulation model. The model parameters are considered as follows and part of the model is made, as shown in Figure 3:

1. Times (input group1):
   - 1-1. Operation times
   - 1-2. Machine setup times
   - 1-3. Transfer times
2. Plans (input group 2 using Excel for entrance in which scrap rate and lead time is considered)
   - 2.1. Charging time
   - 2.2. Bach size

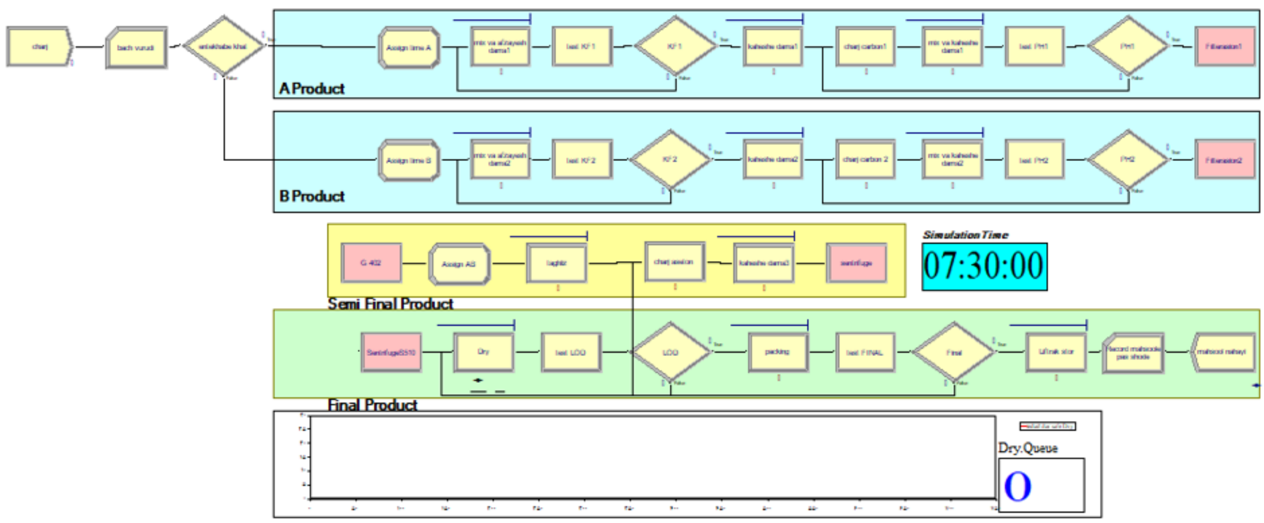

Figure 3. Part of the simulation model

In this study, better communicate with the users, an Excel file has been designed according to the Arena information entry instructions, the information of arrival times, the number of them, and their sequence can be done easily with V.B programming and stored in related arrays which makes it easy to examine different scenarios.

The model is run for 270 days (working day per year) and results are as follow:

1- The products cycle time

2- The difference between the scheduled time and real-time

3- Utilization rate of resources including machines, operators, and Q.C. laboratories

4- Number of batches waiting in places where several batches can enter

5- Waiting time in bottleneck stations in places where several batches can enter

The simulation results are sent to an Excel file and the condition of the bottlenecks and the amount of resource utilization are reviewed and analyzed, the example of which is given in Table 2.

Then, based on the results, the following steps are performed to optimize the model:

1- First, after the implementation of the model, it should be determined which problem is hidden to increase the production throughout.

2- If the problem is with the sequence, scheduling strategies should be used, but the result of our model did not reach this issue. The quest should be used to optimize the mathematical model. Figure 4 shows the best result achieved in the 15th run in which min WIP is 6 batch, average WIP in bottleneck is 0.4 and output is 55 showing a very good result as compared to 49 in the previous period.

Table 2. Model results sample in excel

Bach number	Number of day	A,B product out time	Number of day in simi final	Semi final out time	Dryer number in queue	sentrifuge number in queue	kaheshe dama3 number in queue
1	1	14:59	2	19:55:00	0	0	0
2	1	23:30:00	3	07:17:00	1	0	1
3	2	18:19:00	3	17:19:00	1	0	0
4	3	04:09:00	4	00:53:00	2	0	1
5	3	15:20:00	4	22:28:00	2	1	2
6	4	09:21:00	5	07:09:00	3	0	0
7	4	14:58:00	5	23:42:00	3	1	1
8	5	02:12:00	6	04:27:00	4	2	1
9	5	17:23:00	6	15:30:00	3	1	1
10	6	02:29:00	6	23:32:00	6	2	0

5.2 Model Verification and Validation

After the computer model is made and parameters such as times, resources, schedule information have entered the model, the verification and validation must be checked. Matching the built model with the model maker's mind is done using a digital questionnaire and reviewing by planning experts, and by eliminating the problems announced by them, and then the built model is used.

Simulation 15

Objective Summary	
Objective	**Status**
6.133628	Feasible

Control Summary				
Control Na	**Type**	**Low Bound**	**Solution**	**High Bound**
FBD3	Discrete	1	2	2
G402	Discrete	1	1	2
G405	Discrete	1	2	2
senterifuge	Discrete	1	2	2
Tanker	Discrete	1	1	2

Response Summary	
Response Name	**Value**
A product.WIP	6.133628
Dry.Queue.NumberInQueue	0.360688
Record mahsoolepas shode	55

Constraint Summary					
Constraint Na	**Type**	**Status**	**Left Side**	**Operator**	**Right Side**
New Constraint	Linear	Feasible	2.000000	<=	2.000000
New Constraint	Linear	Feasible	3.000000	<=	3.000000
New Constraint	Non Linear	Feasible	0.360688	<=	2.000000

Figure 4. Solution for the problem

To check the validity of the model with a real system, this model is implemented for 270 working days and the results are checked with the past production data, which showed 83% similarity. Table 3 is ANOVA for the past result (12 months), model solution, and actual outputs.

Table 3: Analysis of Variance (ANOVA)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
year	2	24904	12452	0.18	0.832
Error	33	2224633	67413		
Total	35	2249537			

6. Conclusion

We use simulation-based optimization to combine concepts of optimization operations and computer simulations in which we have increased the utilization to achieve the two goals: optimal use of resources and optimization of output. To optimize usage of the resources, as you can see in Figure 5, the leveling of resources has occurred with the movement of resources (according to Opt. Quest output) and in addition to increasing the amount of utilization, the amount of output has also increased. In a certain period, the number of production batches has increased by 12%, which shows a favorable result in solving FSSP.

To extend this research, study the effect of reactors layouts because of the significant impact on the rate of utilization should be done also to reduce the variation of the time deviation, calculation of the amount of stability and process capability and its impact on this issue should be done to move closer to model real-life dynamic scheduling problems.

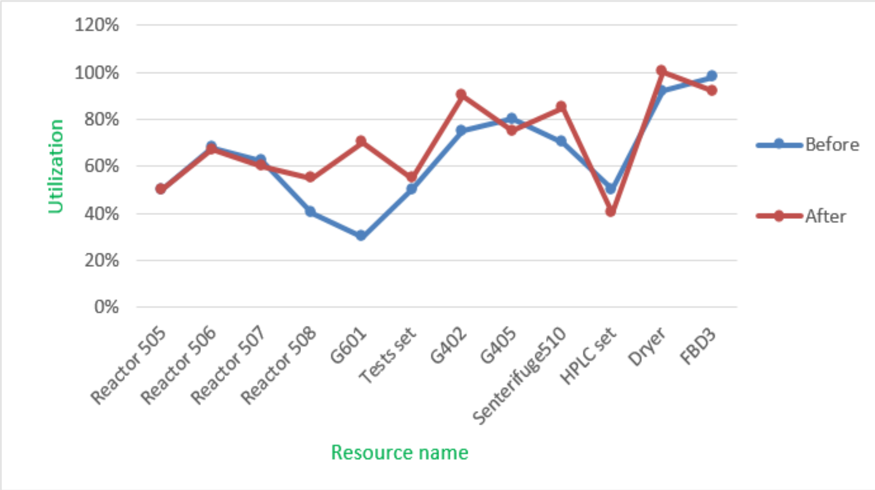

Figure 5. Resource's utilization

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