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OPTIMIZATION OF MANUFACTURING ENTERPRISE COLLABORATION WITH SUBCONTRACTORS THROUGH PRODUCTION PROCESS SIMULATION

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Abstract: This paper presents a simulation-based model aimed at optimizing the outsourcing of production tasks to external subcontractors, focusing on minimizing costs and production times. The study explores a manufacturing scenario where a company utilizes both in-house and subcontractor resources for machining metal components. A simulation model was developed in FlexSim, employing advanced tools such as the OptQuest optimizer to analyze various scenarios of production allocation. Parameters like production cost, machine utilization, and task completion times were modelled and evaluated. The results showcase the effectiveness of simulation models in identifying optimal production strategies, balancing cost-efficiency with operational flexibility. The findings emphasize the utility of such tools for decision-making in production management, providing insights into resource allocation and performance improvement.
Keywords: Production Management, FlexSim, Simulation, Optimization

1. INTRODUCTION

Collaboration between manufacturing enterprises and external entities in production processes plays an increasingly significant role in effective production management, especially under dynamic market conditions. Such cooperation enables companies to better adapt to demand fluctuations, shorten product life cycles, and execute orders that exceed the internal capacities of their facilities. However, this type of collaboration requires careful consideration of factors such as raw material accounting, receipt of finished products, transportation and storage costs, and the integration of subcontractors' schedules within the overall production plan (Daroń, 2022; Krynke, 2021; Krynke and Klimecka-Tatar, 2022; Nowakowska-Grunt and Mazur, 2015). Moreover, the implementation of a circular economy business model further enhances such collaboration by emphasizing resource efficiency and waste minimization, which can significantly improve operational effectiveness (Ingaldi and Ulewicz, 2024).

Dynamic technological advancements and increasing competition have prompted companies to increasingly adopt decision-support tools. In addition to traditional analytical methods, simulation tools are gaining prominence, as they allow for the modeling of production processes in a virtual environment. These tools make it possible to test various scenarios of subcontractor cooperation, leading to more informed decisions regarding resource allocation and process organization (Beaverstock et al., 2011; Pawlewski and Anholcer, 2019; Dadi et al., 2021; Jamela, 2024). As highlighted by Poloczek and Oleksiak (2024), computer simulations can effectively evaluate the efficiency of production line expansions, providing key insights for process optimization.

The development of simulation tools such as FlexSim enables the realistic representation of complex production systems by integrating data on manufacturing processes, logistics, and planning. This software allows for the optimization of parameters such as order completion time and total production costs, which are critical under conditions of limited resources and strict time constraints (Krynke, 2023a; Castane et al., 2019; Knop, 2021; Ingaldi, 2022). Simulations within the FlexSim environment are particularly useful when selecting the best course of action, taking into account factors such as operational efficiency and resource utilization.

This article presents a model for manufacturing enterprise collaboration, aimed at optimizing the process of outsourcing production to external subcontractors. The analysis considered criteria for minimizing costs and lead times, directly affecting the efficiency of order fulfillment. The proposed model outlines various production planning scenarios that facilitate the selection of the most optimal configuration. Such approaches align with previous studies emphasizing the economic advantages of optimizing subcontractor collaboration and integrating automated systems into production processes (Ulewicz and Mazur, 2019). The simulations were conducted using FlexSim software, enabling a detailed analysis of material flows and an evaluation of process performance in relation to the defined objectives.

2. SIMULATION MODEL DEVELOPMENT – CASE STUDY

As part of the research analysis, the following problem was examined. A company specializing in the production of metal components operates a manufacturing facility where machining is performed on various types of machines. To increase production efficiency and flexibility, the company can utilize the services of external entities offering machining on specialized CNC machines. Machines M1 and M2 are owned by the company, while machines M3, M4, and M5 represent the production systems of external subcontractors. The manufacturing costs and efficiencies of each machine are summarized in Table 1.

The company must produce a specified quantity of components within a defined timeframe while minimizing production costs. The challenge lies in appropriately distributing production between its own machines and the services offered by external entities to achieve maximum efficiency at minimal cost. This task requires analyzing various scenarios of production allocation between internal resources (machines) and external subcontractors to optimize the manufacturing process and minimize expenses (Krynke, 2023b; Qawaqzeh et al., 2021; Siwiec et al., 2022; Dziuba et al., 2011).

In this example, the production targets are set at 1,000 units of Product Type 1, 1,500 units of Type 2, and 2,000 units of Type 3. The entire production must be completed within one month, assuming the facilities operate a single shift, five days a week.

The manufacturing process for the finished products can be represented in the FlexSim environment using the model shown in Figure 1. This model utilizes standard objects from the program's library, programmed according to the task's conditions. Intuitively, the Processor objects should represent the machines in this scenario. In the model, each

Processor corresponds to one of the machines, M1 ÷ M5. The process time for each machine is set according to its efficiency (Table 1) (Daroń, 2022; Saragih et al., 2020; Krynke, 2021).

Table 1
Manufacturing costs and efficiencies of individual machines

Factory	**Machine**	**Product Type**	**Production Time [min]**	**Cost [monetary units/pcs.]**
F1	M1	1	6	10
		2	5	11
		3	8	12
	M2	1	4	13
		2	6	15
		3	7	11
F2	M3	1	5	13
		2	4	15
		3	6	17
F3	M4	1	4	15
		2	3.5	16
		3	5	19
F4	M5	1	4	14
		2	5	14
		3	5	19

Source: own study

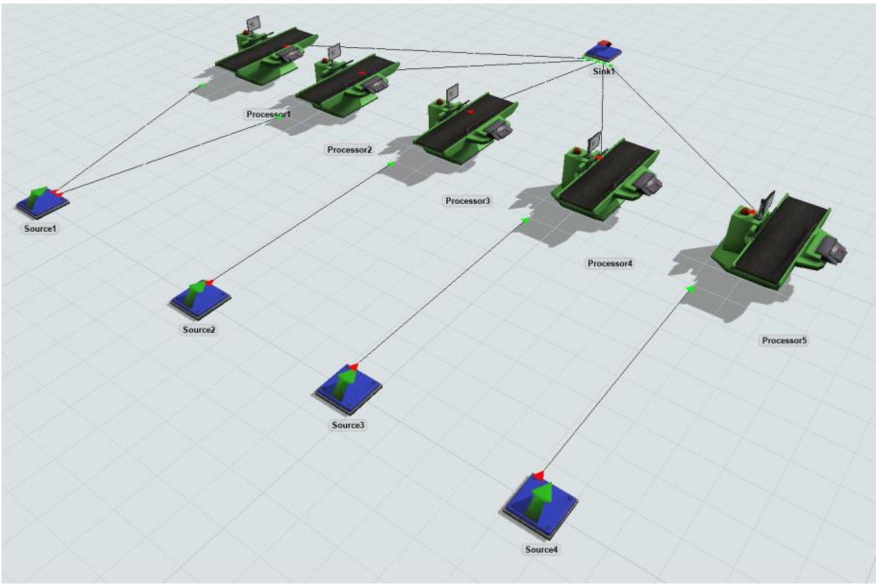

Fig. 1. Simulation Model for the Discussed Problem

The Source objects, typically generators of multiple flow elements, operate in "Arrival Sequence" mode in this model. Here, a flow element symbolizes a product of a specific type. This variable will be utilized in the optimization process, serving as the point where the optimizer generates results from successive iterations. This variable is expressed

through parameters defining the quantities of each type of product sent to individual facilities.To define these parameters, they must be added from the Toolbox library. Then, in the "Value" column, set the variable type to Integer and establish boundaries ranging from 0 to the maximum number of produced items for each type. Next, use the probe to point to *Source1* > *Variables* > *Sequence* > *Arrival1* > *Quantity* (Fig. 2).
There are 12 input parameters in total since there are four facilities, each capable of producing three types of products.

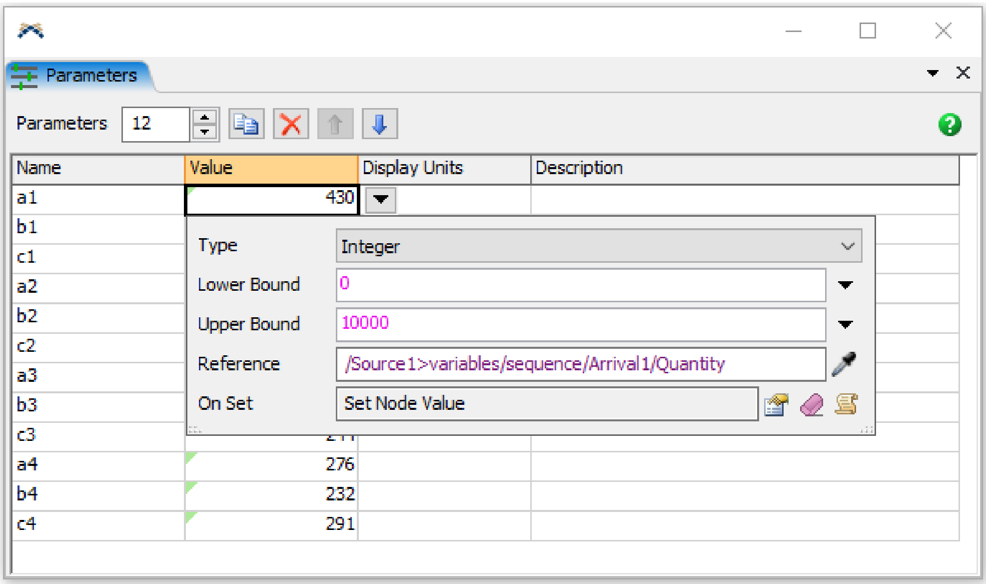

Fig. 2. Definition of input variables

The objective function is defined as the cost of operating processors, representing the machines. Machine costs depend on the type of product being processed.
To calculate the operational cost of all processors, the Financial Analysis tool in FlexSim is a convenient option. This tool allows for defining the cost for each processor, accounting for the type of processed product per Table 1. The output variable (objective function) is the total production cost, read from the Financial Analysis chart. This parameter is defined by adding it from the Toolbox library as a Performance Measure variable (cost). It must be assigned to the objective function as Financial Analysis - Total (Fig. 3).

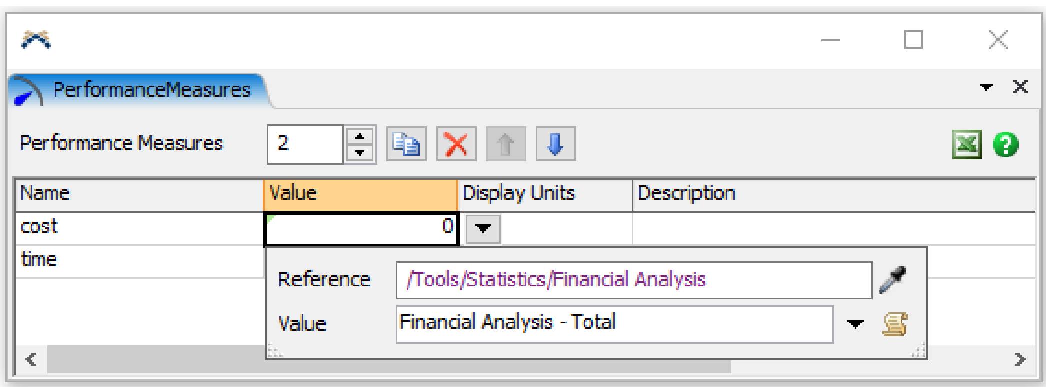

Fig. 3. Definition of the objective function – the output variable for total costs read from Financial Analysis – Total

The objective function in this task is minimized since the company aims to reduce costs. Additionally, the total task completion time is minimized. However, system time is not available as a ready-made function in the dropdown list. Instead, a custom code is required for an additional Performance Measure (time) variable (Fig. 3). The following code should be entered in the code editor window:

```
/**Custom Code*/
treenode datanode = parnode(1);
return time();
```

Boundary conditions and constraints must also be specified (Fig. 4) regarding production batch sizes and the potential production capacities of individual facilities. The optimization direction is set to minimize production costs and time. The objective weighting option is selected, meaning FlexSim's optimizer will strive to minimize costs as much as possible while achieving moderate minimization of order completion time (Fig. 5).

Constraints

	Equation
Constraint 1	[a1]+[a2]+[a3]+[a4]=1000
Constraint 2	[b1]+[b2]+[b3]+[b4]=1500
Constraint 3	[c1]+[c2]+[c3]+[c4]=2000

Fig. 4. Boundary conditions for batch sizes and production capacity of individual plants

Objectives

	Active	Function	Direction	Aggregation
Objective 1	✓	[cost [Monetary units]]	Minimize	Maximum
Objective 2	✓	[time [Days]]	Minimize	Mean

Fig. 5. Defining the direction and weight of the optimization objective

To solve the problem, the OptQuest optimizer from OptTek, integrated into the FlexSim platform, was used. This tool employs advanced technologies such as neural networks for analyzing and modeling nonlinear relationships and metaheuristic algorithms, including genetic algorithms, simulated annealing, and tabu search. These technologies enable efficient exploration of large solution spaces and avoid local optima.

Thanks to its integration with FlexSim, OptQuest directly optimizes simulation results by generating scenarios tested in the model and analyzing results to adjust search strategies. Its adaptability and forecasting capabilities, based on prior iterations, significantly accelerate finding the best solution (Laguna, 2011).

The optimizer's settings included 40 feasible solutions and a wall time of 100 seconds, meaning the optimizer has a maximum of 100 seconds of real time to find a solution for a single iteration. If no solution is found within this time, it proceeds to the next iteration. The optimizer adjusts the flow element quantities until determining the optimal values, where processor costs are minimized alongside task completion time.

2. RESULTS ANALYSIS

After running and analyzing the simulation model, the following results were obtained. Figure 6 shows the front of 40 optimal solutions, where each solution represents a compromise between costs and production lead time. These results enable the assessment of the efficiency of the proposed distribution of production between internal resources and external services, considering both cost minimization and order lead time reduction. The analysis allows for the identification of optimal production allocation scenarios that meet the boundary conditions and constraints outlined in the previous chapters. The 10 best solutions, marked with a star, are considered optimal, taking into account both cost and lead time minimization. These solutions represent the most efficient scenarios, achieving the best cost-to-time ratio while simultaneously meeting the established constraints on production capacity and batch size.

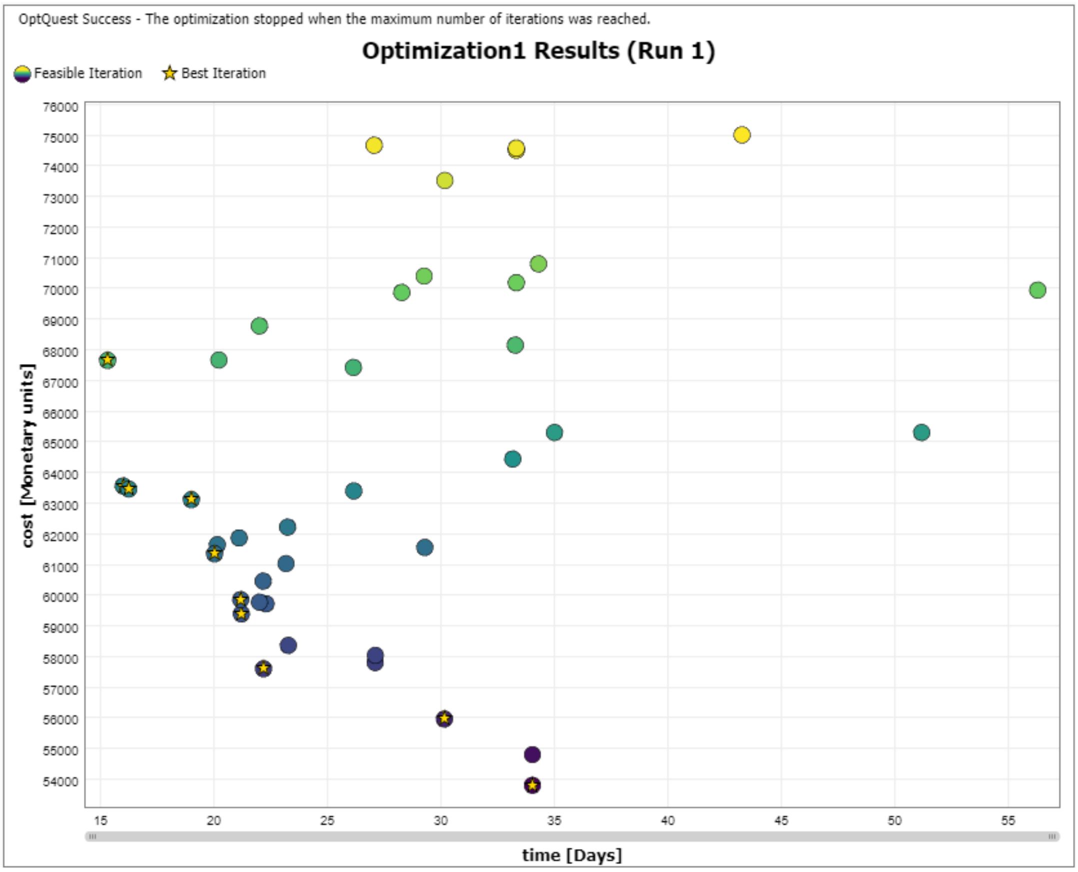

Fig. 6. Front of Optimal Solutions

Table 2 presents detailed results for all 10 optimal solutions, showing how production should be allocated across individual plants. This analysis allows for a precise determination of how to assign production to both internal machines and external services in order to achieve the best possible efficiency while minimizing costs and time. These results provide valuable guidance for decision-making regarding resource allocation and the optimization of production processes within the company.

Figure 7 illustrates the utilization of individual processors, which represent the production systems of the plants, considering both internal company resources and external contractors. Processors 1 and 2 correspond to the company's internal production systems, while the remaining processors represent external contractors to whom part of the production was outsourced. The analysis of this figure shows that the company's production system (processors 1 and 2) is the most heavily utilized, indicating intense use of internal resources to fulfill the orders. The processor representing the last external contractor also shows high utilization, suggesting that the external supplier is responsible for a significant portion of the production. The remaining production systems are less utilized, which may indicate a more balanced allocation of production between the different plants.

Table 2
Results for all 10 optimal solutions, showing the distribution of production across individual plants

ID	a1	b1	c1	a2	b2	c2	a3	b3	c3	a4	b4	c4	cost [Monetary units]	time [Days]
1	430	599	833	117	46	632	177	623	244	276	232	291	63556	16.01
5	250	375	500	250	375	500	250	375	500	250	375	500	67651	15.33
14	0	1290	1945	0	0	55	0	210	0	1000	0	0	55959	30.15
17	250	599	1077	117	0	632	357	901	0	276	0	291	63111	19.01
25	0	1500	2000	1000	0	0	0	0	0	0	0	0	53798	34.03
31	228	0	1984	772	582	0	0	0	0	0	918	16	57596	22.19
32	**0**	**11**	**1775**	**0**	**734**	**0**	**251**	**0**	**225**	**749**	**755**	**0**	**61345**	**20.04**
37	654	0	1590	344	0	0	2	605	410	0	895	0	59385	21.21
38	0	496	1183	0	500	384	167	0	377	833	504	56	63456	16.26
40	0	0	2000	0	1201	0	418	0	0	582	299	0	59851	21.19

Source: own study

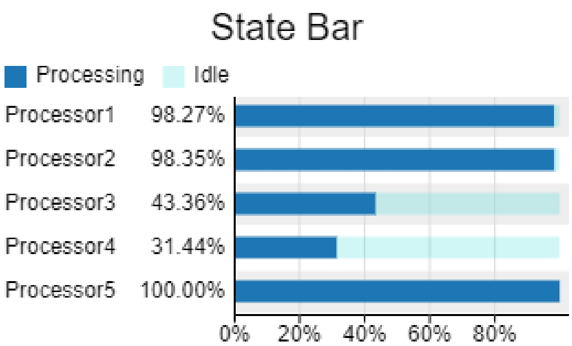

Fig. 7. Utilization of individual processors representing the production systems of the plants

Figure 8 illustrates the production cycle for each plant, presenting the production flow over time. The horizontal lines on the chart represent production breaks resulting from the absence of production during the second and third shifts and the free weekends. This chart allows for a detailed assessment of the efficiency of each plant during different periods, considering times when production is halted due to breaks in the work schedule. From this chart, conclusions can be drawn regarding the organization of work at each plant, identifying moments when production is paused and evaluating how these breaks impact overall manufacturing efficiency.

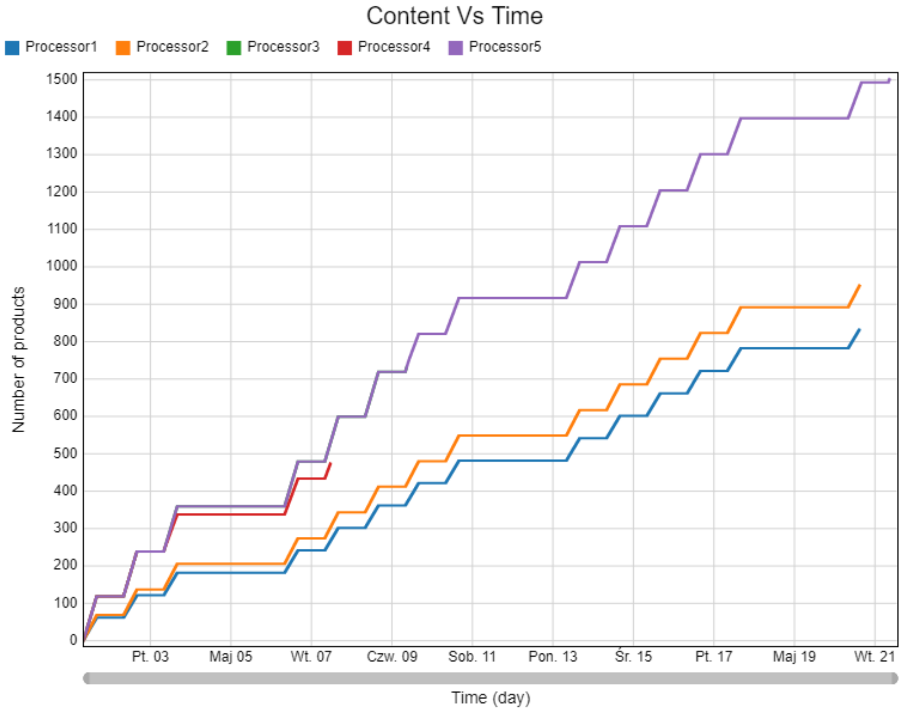

Fig. 8. Manufacturing cycle diagram showing the production timeline for scenario 32

3. CONCLUSION

The article presents a simulation model aimed at optimizing production in a company engaged in the machining of metal components. The company faces the challenge of efficiently distributing production between its own machinery resources and external CNC service providers. The simulation model built in FlexSim enables the analysis of various production allocation scenarios to minimize both costs and order lead time. The production of 1,000 units of product type 1, 1,500 units of type 2, and 2,000 units of type 3 was considered, with the assumption that the total production time would not exceed one month. The optimization utilizes the OptQuest tool, which employs advanced methods such as genetic algorithms to effectively search for optimal solutions, taking both costs and lead time into account. As a result of the analysis, 40 optimal solutions were obtained, representing a compromise between cost and production lead time. The top 10 solutions were highlighted based on the most favorable cost-to-time ratio. The analysis results provide valuable insights into production allocation across different plants, allowing the company to make decisions that lead to maximum production efficiency with minimal costs and order completion time.

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