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# Tactical manufacturing capacity planning based on discrete event simulation and throughput accounting: A case study of medium sized production enterprise

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**A B S T R A C T**

The article presents the application of the original methodology to support tactical capacity planning in a medium-sized manufacturing company. Its essence is to support medium-term decisions regarding the development of the production system through economic assessment of potential change scenarios. It has been assumed that the developed methodology should be adapted to small and medium-sized enterprises (SMEs). Due to their flexibility, they usually have limited time for decision-making, and due to limited financial resources, they rely on internal competencies. The proposed approach that does not require mastery of mathematical modelling but allows streamlining capacity planning decisions. It uses the reasoning of throughput accounting (TA) supported by data obtained based on discrete event simulation (DES). Using these related tools in the design and analysis of change scenarios, make it possible for SME managers to make a rational decision regarding the development of the production system. Case studies conducted in a roof window manufacturing company showed the methodology. The application example presented in the article includes seven change scenarios analyzed based on computer simulations by the software Tecnomatix Plant Simulation. The implementation of the approach under real conditions has shown that a rational decision-making process is possible over time scale and with the resources available to SMEs for this type of decision.

**A R T I C L E   I N F O**

*Keywords:*
Decision process;
Capacity planning;
Discrete event simulation (DES);
Throughput accounting (TA);
Plant simulation;
Small and medium-sized enterprises (SME);
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## 1. Introduction

Balancing supply-to-demand production capacity is a key consideration to ensure the viability of the company's operating activities. The need for changes in the manufacturing system is dictated by adapting to increasingly precisely projected demand [1], the increasing possibility of automating and robotizing monotonous work requiring physical exertion [2], implementing technologies in the field of Industry 4.0 that significantly improve production processes [3]. Rational implementation of changes requires an understanding of their consequences. The right decisions allow maintaining the right balance between system capacity and production costs. Production capacity is the most strategic internal capability that manufacturing firms must create, sustain and plan for. Capacity management aims to ensure that a manufacturer has the ‘right’ capacity to act within a complex structure and how best to ‘utilise’ their internal capabilities [4]. They refer to the amount of output that a system is capable of achieving over a specific period of time [5].

Both capacity expansion and contraction are called capacity planning [6]. The level of production capacity directly influences on the one hand the possibility of carrying out orders and on the other hand the level of fixed costs of the company. Therefore, the cost of production is determined by the level of capacity utilisation and thus its match with demand [7]. With regard to the medium - term capacity planning, appropriate capacity planning methods are key, which assess the consequences of these decisions on the production system [8].

Observations made in small and medium-sized manufacturing companies indicate managers are under pressure to ensure that the decision-making process for tactical capacity planning does not exceed a few weeks. It includes an analysis of the production situation leading to the development of change scenarios and their assessment, which results in a recommendation for investments. These are issues so complex that leaving their intuition even an experienced manager is irrational. The literature on the problem of capacity planning offers solutions based on mathematical modelling and/or artificial intelligence. There are lack of approaches that would ensure a rational solution to the problem, even with a reduction in its optimization. As part of the presented research, it sought a method that would enable the decision-making process to be carried out within a few weeks using the knowledge available to a typical process engineer. Its essence is to recommend solutions to the problem of tactical capacity planning, considering production and economic issues. The article attempts to respond to this challenge by proposing a tactical capacity planning method verified by a case study of a medium-sized roof window company. The essence of the suggested approach is to combine discrete event simulation (DES) with throughput accounting (TA). DES allows analysing the current production situation and aids to design change scenarios. TA is used to diagnose financial effects based on data from simulation experiments and estimated costs of implementing changes.

The proposed approach to the capacity planning issue is assigned primarily to small and medium-sized enterprises (SMEs). Limited time and competencies inhibit them to use methods based on mathematical programming or artificial intelligence, which are discussed in the next chapter of the article. It is also discussed in it the new opportunities for SMEs give by DES software development. Chapter three provides a detailed description of the problem, research methods, and the starting state of the analyzed manufacturing system. Chapter four shows the step-by-step process of planning of tactical capacity according to the proposed method. Chapter five discusses the significance of the results got in a broader context relating to operational management. Chapter six outlines the advantages of the proposed method and points to limitations in its application.

## 2. Theoretical background

### 2.1 Overview of tactical capacity planning methods

Capacity can be defined as the total productive capability of all the utilized productive resources including workforce and machinery [9]. Capacity management aims to ensure that a manufacturer has the 'right' capacity to act within a complex structure and how best to 'utilise' their internal capabilities [4]. The capacity decisions can be made in all decision-making hierarchies: strategic, tactical and operational [9]. The scope of tactical capacity planning decisions includes [10]:

- considering the mid-term demand, to decide whether the capacity of the existing factories should be expanded by buying new auxiliary tools (purchase or replace bottleneck machines; purchase or replace auxiliary tools),
- considering the mid-term demand, to decide the best portfolio of products (decide the best portfolio of products).

The analysis in this article is limited to the first scope of decisions oriented towards increasing production capacity through changes in the production process.

Many of the solutions to the capacity planning problem presented in the literature are based on the Integer Linear Programming (LP) or Mixed Integer Programming (MIP) models, [11, 12]. They work very well in large, automated companies, as well as with production allocation problems in various production facilities [13], or the combination of strategic and tactical decisions in the design of the distribution network including storage capacity, [14]. The problem is the adequacy of linear models, which is often not satisfactory. Complex systems may not reflect the decision-making situation well enough when uncertainties need to be taken into account. In such cases, models based on stochastic programming [15] are used. The literature reports good results in the use of such an approach [16], but the high complexity and difficulty of using them leads to the search for metaheuristic algorithms combining deterministic and stochastic approaches [17].

A large group of tactical capacity planning solutions is based on combining simulation and optimization techniques. Examples include the use of artificial neural networks in connection with genetic neural networks [18], or the link between genetic algorithms and Monte Carlo simulation [19]. However, the use of such solutions requires advanced knowledge and time, which is why the publications presenting them refer to industries dominated by large companies. It should also be noted that hasty imposition in the model of certain assumptions may lead to a situation where the real problem of the company is not solved.

The latest capacity planning solutions take advantage of the opportunities offered by Industry 4.0 application. The capacity planning model for prefabricated housebuilding elements uses real-time data entry to improve assembly line performance planning [20]. This approach develops short-term capacity equalization in make-to-order production systems [21]. Small and medium-sized enterprises, however, generally do not have sufficient resources to collect large amounts of data or do not have the skills to process it [22]. The solution proposed for them is a computer simulation, increasingly recommended in publications based on practical problems presented on the basis of a case study of enterprises [23].

### 2.2 Discrete event simulation in manufacturing capacity development

Simulations represent imitation of some process in the real world. Process simulation often requires generating a model that will represent the key characteristics of the selected system or process and will present its behaviour [24].

Discrete event simulation (DES) is an instrument for analysing dynamic processes taking into account stochastic parameters and uncertain events [25]. Simulation modelling aims to qualitatively or quantitatively support decisions by building a model of a real system and experimenting with that model [26]. The increasing importance of simulation methods in solving complex production problems is demonstrated by the growing number of studies in this field [27]. Among them, methods based on discrete event simulation [28] occupy an important place. They support the resolution of many different capacity planning problems, such as:

- configuration of flexible modular mounting systems [29];
- matching capacity to uncertain demand for hospitals and other healthcare providers [30];
- analysis of employee productivity in a production process with high variability due to low level of automation [31];
- decision-making tool in the complex production configuration of the automotive assembly line [32].

DES modelling uses the software of various types. Commercial systems such as Tecnomatix Plant Simulation, ARENA, Enterprise Dynamics and FlexSim are the most popular among industrial engineers. The first was used in the presented studies because it provides advanced options for each component of the model to accurately match it to the actual production system. Also not without significance is the extensive help in the form of online guides and training offered by the manufacturer and the community using this software. Open source systems such as Salabim, JaamSim, whose usability is compared to commercial systems [33] are also becoming increasingly popular.

The greatest benefit of using DES in capacity planning is the ability to represent even complex processes without losing the accuracy of the results or significantly increasing the calculation time. Conducting experiments using DES provides an understanding of the system's behaviour before it is built, the detection of unexpected incompatibilities, the ability to investigate various applications of case scenarios [34]. However, it should be remembered that simulation models only allow you to predict the outcome of different scenarios. Thus, the "best" solution is chosen from the scenarios analysed, not from all possible, in contradistinction to optimization models, where the "best of all" is expected. The use of computer simulation, therefore, does not guarantee an optimal solution to the problem of capacity planning.

## 3. Problem statement and used methodology

### 3.1 Problem statement

A research gap is identified regarding the use of decision support tools to solve tactical planning problems in real-world production conditions [35]. The article considers the problem of capacity planning in the company manufacturing roof windows. It is one of the manufacturing plants for a well-known brand in Europe. Of the 150 people employed, 122 serve production and warehouses, and the rest are technical and administrative staff. The company's current production capacity is 800 pcs/business day when working on two shifts. The plant received from the headquarters (from the window distributor) a question about the possibility of increasing production for half a year to 1100 pcs/day, a decision must be made within 1 month, and possible changes made within 3 months. At the moment, the company makes such decisions based on the opinions of internal specialists. The analyses are limited to a specific brainstorming session in which 2-3 variants of change are considered. This approach, in the opinion of managers, is insufficient. They would like the decision-making process for capacity planning to be based on a structured decision-making process supported by reports containing reasonable estimates of the effects of change. The analysis time offered by consulting companies is not adequate to the requirements of tactical planning. In addition, the company has experienced and committed employees involved in the development of its competencies.

### 3.2 Research objectives

The practical purpose of the research was to find an answer to the question of how the tactical capacity planning decision-making process should proceed so that it could be used by the window manufacturer. In a broader context, the research aims to propose a capacity planning methodology that is useful for the resources available to small and medium-sized enterprises. This includes providing theoretical guidance on how to approach the design of organisational changes and to assess their production and financial performance in the real world. Combining them into an orderly methodology is intended to promote rationalisation of the decision-making process, taking into account the constraints typical of small and medium-sized enterprises. Qualitative studies that answer the 'how' question require an understanding of the conditions for implementing the methodology and should therefore be supported by case study methods [36].

### 3.3 Methodology

Most of these scientific publications in the field of capacity management seek to obtain practical results by confronting existing theories with problems occurring in industrial reality. In the field of operations management, case research is seen as one of the most powerful methods [37]. The case study method is very often used in the study of production systems because it allows for a comprehensive and broad view of complex issues in highly diverse environments [38]. The research presented in the article leads to the development of solutions that are valuable from a practical point of view while generating theoretical knowledge. Efforts were made to present in detail the data collected during the analysis of the current situation of the production system. They were collected by:

- observation of the production system by the investigator, which made it possible to identify the elements of the system and understand the connections between them,
- testing of production documents, including, in particular, reports from the SAP ERP system,
- measurements made in the production system for the preparation of its computer model,
- semi-structured interviews on production system constraints and unstructured interviews relating to the company's capacity planning capabilities and needs,
- simulation experiments leading to verification of the developed model.

The data collected in this way was used to:

- development of a computer model illustrating the current state of the production system,
- formulate assumptions for change scenarios,
- develop a concept for evaluating change scenarios.

In the second phase of the study, the following research techniques were used to develop and analyse change scenarios:

- participant observation when designing change scenarios,
- experiments based on computer simulation to determine the production effects of a given change scenario,
- structured interview on estimating the financial parameters of the change scenario.

The aim of the second phase was to characterise the scenarios of change in order to recommend one of them or to reject the proposal to increase production capacity.

### 3.4 Model of current state of roof window plant

The case study involved a roof window manufacturer that is part of a global network of sales, production and services. The article only analyses the assembly line bypassing the process of painting components and material handling, because their flexibility is much higher than the assembly process and allows a much larger volume of production. There are 20 workstations on the line. The daily production plan is generated by the SAP ERP system, which determines the order in which orders are run. The plant works two shifts five days a week. The current demand volume is 800 units/day. In the system, you can distinguish 5 sections presented in Fig.1. The description of which is given in Table 1.

The upper part of Fig. 1 shows the layout of the entire assembly line, which distinguishes sections such as interior wing assembly line (In_sash), external wing assembly line (out_sash), installation station of both window wings (Sash_assembly), window assembly section (pane_assembly), packaging section (Packaging). The lower part of Fig. 1 presents the positions in the different sections of the production line. The model was made using Tecnomatix Plant Simulations by Siemens software.

In the section where the outer wing is joined (sash_assembly) and in the section where the glass is inserted, there is a large share of manual work. The triangular distribution was used for its modelling. It is defined by three parameters (c, a, b), where the most probable value is c, the minimum value is a and the maximum value is b. In Tecnomatix Plant Simulation triangular distribution is called triangle distribution. Table 1 describes the object parameters in each section of the model and describes them. This data allows you to recreate the model in any DES environment.

Based on production reports from SAP – ERP, it is assumed that the frequency of overarching best aggregates the batch size of 25 units. In practice, the size of the production batches varies and is a multiple of 5 pcs.

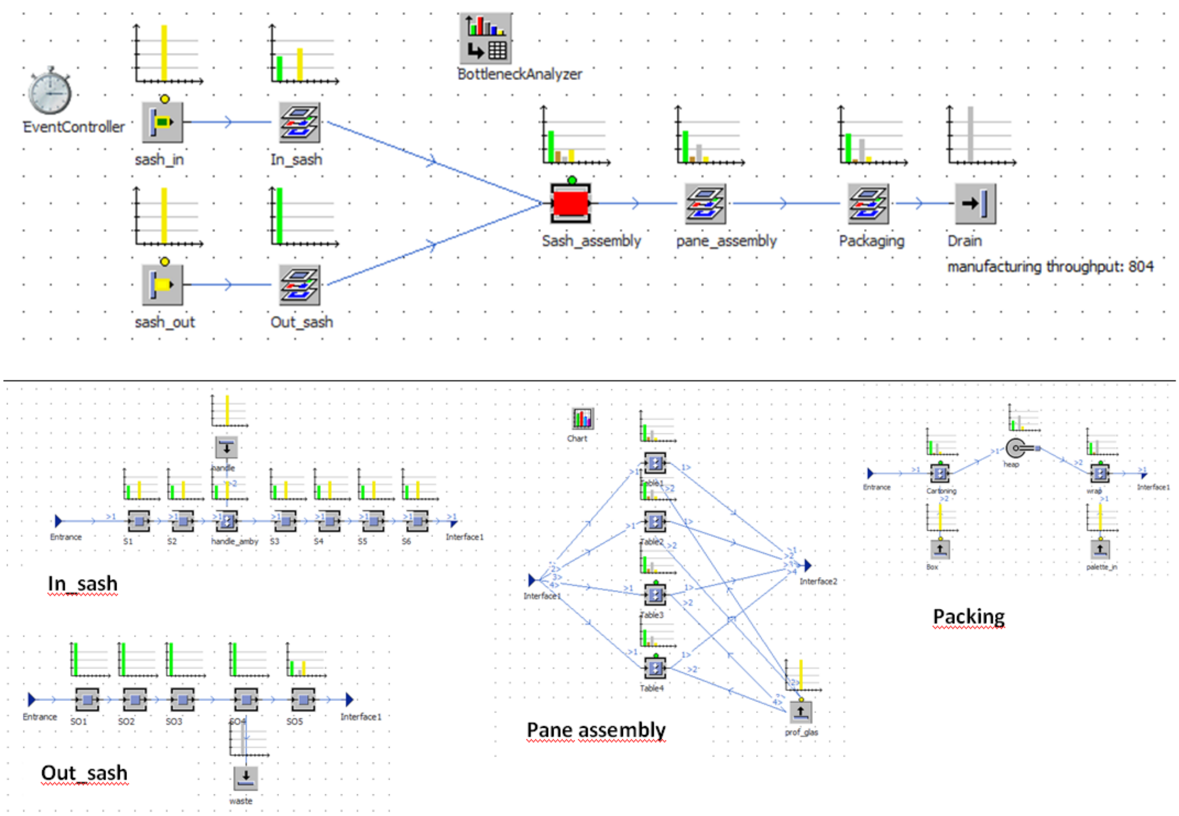



**Fig. 1** Assembly line model of the roof window manufacturer made in Technomatix Plant Simulation system

**Table 1** Description of the individual positions of the modelled production process

| Section description | Model marking | Section characteristics |
|---|---|---|
| Installation of internal wing elements | *In_sash*<br>One worker on each station | A string of 7 mounting tables bound by roller relays.<br>Processing time for each position 30 s. |
| Installation of external wing elements | *Out_sash*<br>One worker on each station | A string of 7 mounting tables bound by roller relays.<br>Processing time for each position 30 s.<br>In position SO4 1 % waste. |
| Installation of the outer and inner wings | *Sash_assembly*<br>Two cooperated workers | Processing time: triangle (0:40, 0:20, 1:00)<br>Set-up time: triangle (5:30, 4:15, 6:00)<br>Set-up after 25 parts before next part |
| Installation of the glass | *Pane_assembly*<br><br>One worker on each station | 4 independent stations equipped with slatted glass mounting tables and aluminium profile mounting machines.<br>Processing time: triangle (2:10, 1:30, 4:00)<br>Set-up time: triangle (8:00, 6:00, 15:00)<br>Set-up after 25 parts before next part. |
| Packing | Packing<br><br>One worker on each station | Equipment assembly: cartoning machine, robot for stacking windows into packages of 5 pieces (heap), foiling machine and preparation of packages for transport (wrap). |
| | cartoning | Processing time: 35 s<br>Set-up time: 1 min<br>Set-up after 25 parts before next part |
| | heap | Loading time 5 s<br>Unloading time 10 s |
| | wrap | Processing time: 30 s<br>Set-up time: triangle 20 s<br>Set-up after 5 parts before next part. |

# 4. Results and discussion: A case study for designing and analysing changes in the production system

## 4.1 Proposed approach to designing change scenarios in manufacturing system

The proposed methodology for capacity planning is largely based on the Theory of Constraints logic. If demand exceeds the company's capacity in terms of production volume and is of a physical nature, it identifies a resource constraint [39]. The process of improving the production system should begin with such a limitation called a bottleneck [40]. The next step in improving the production system is to determine how to exploit the bottleneck. Typically, there are more than a dozen potential improvement scenarios focusing on bottlenecks [38]. Their development takes time and is determined by the experience and creativity of the management team.
Because of the limited time, it is proposed to design change scenarios taking into account the decreasing likelihood of their success. It is assumed that it is due to difficulties relating to the organisational effort of the staff and the risks associated with the novelty of the changes, which affect the uncertainty about the expected results and the error of financial estimates. The following order in which change scenarios are formulated is proposed:

- Balance the production flow to a consistent rate imposed by the bottleneck.
- Elimination of losses on bottleneck according to Lean Production methods.
- Introduction of cooperation and outsourcing in the production process.
- Introducing incremental and radical innovations in the production process.

## 4.2 Assessment of production parameters of changes scenarios

Bottleneck-focused improvements are typically strongly linked to other components of the production system, so the capacity increase of the entire production system should be estimated as a basis for their implementation. The use of DES in the proposed methodology is not limited to analysing the current state of the manufacturing system but is extended to include an analysis of future conditions on the basis of "what if" experiments. Table 2 presents a summary of the analysed scenarios of change with scenario details, where $t_i$ means processing time and $t_{su}$ means set-up time. In addition, the scenario resulting from the frequent belief that in the event of a shortage of capacity, it is sufficient to install a new manufacturing unit, a scenario marked with the letter B, which involves the duplication of the mounting position of the inner wing and the outer roof window.

**Table 2** Summary of analysed scenarios of changes in the production system

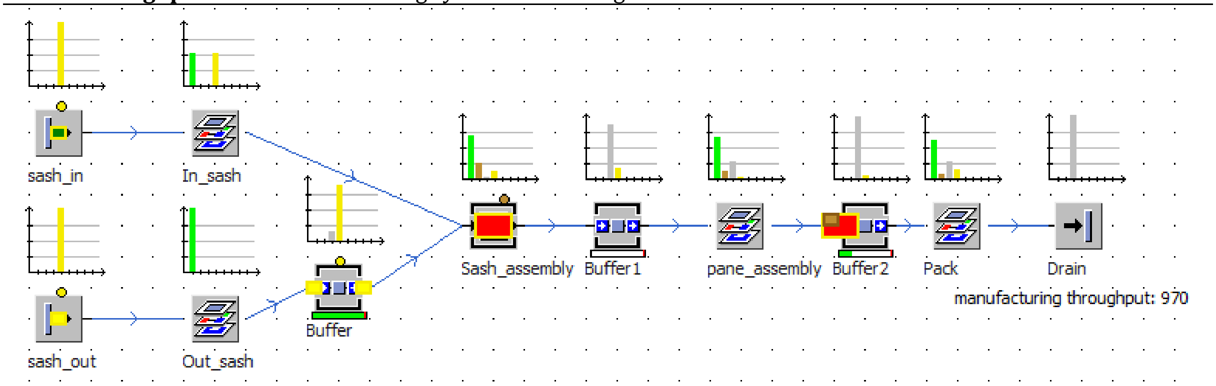
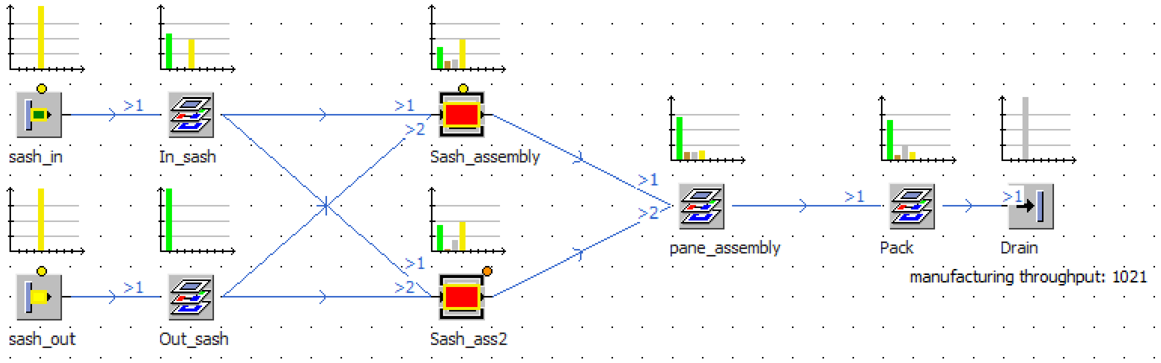
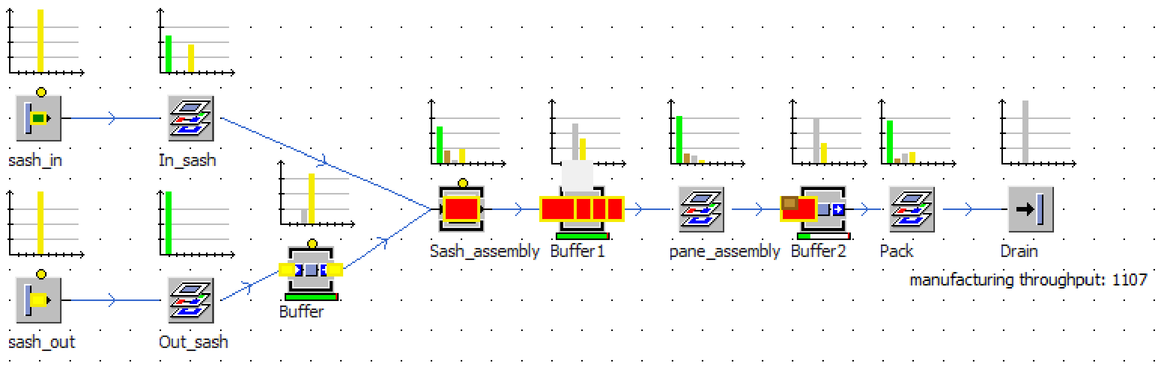
| |
|---|
| **A:** Put the three buffers into the manufacturing system for blockade limitation on the stations: *sash_assembly* and *pane_assembly*. Buffers are on the tables with roller conveyers.<br>**Scenario details:** Buffer capacity = 2, Buffer1 capacity = 4, Buffer2 capacity = 4<br>**Total throughput** of the manufacturing system after changes: 970 roof window |
|  |
| **B:** Duplication the *sash_assembly* station.<br>**Scenario details:** Interposing stadion: Sash_ass2; $t_i$ -> (0:40, 0:20, 1:00)F; $t_{su}$ -> (5:30, 4:15, 6:00)<br>**Total throughput** of the manufacturing system after changes: 1021 roof window |

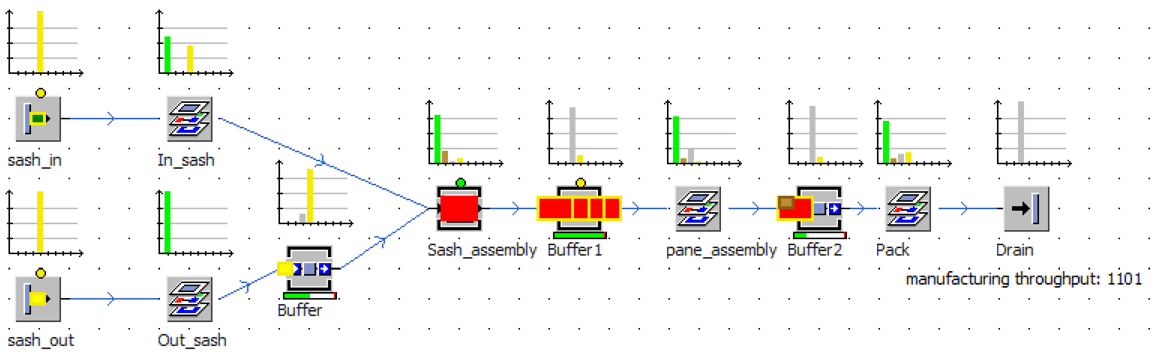
**Table 2** Summary of analysed scenarios of changes in the production system (continuation)




**A+C:** Case A combined with introducing the standardization on the station *sash_assembly* for shortening processing and setup time.
**Scenario details:** Buffer capacity = 2, Buffer1 capacity = 4, Buffer2 capacity = 4, Sash_assembly: $t_i$ -> (0:30, 0:20, 0:40), $t_{su}$ -> (4:00, 3:00, 4:30)
**Total throughput** of the manufacturing system after changes: 1107 roof window

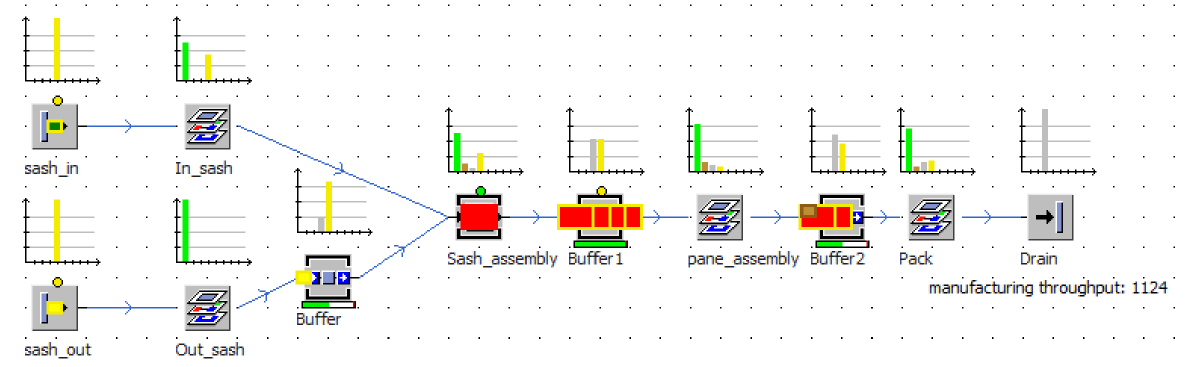



**A+D:** Case A combined with additional worker on pane_assembly, who help in set-up. The scenario assumes panel computer installation, which shows setups ahead.
**Scenario details:** Buffer capacity 2, Buffer1 capacity = 4, Buffer2 capacity = 4, Sash_assembly: $t_{su}$ -> (4:00, 3:00, 4:30), Table1-Table4: $t_{su}$ -> (4:00, 3:00, 7:00)
**Total throughput** of the manufacturing system after changes: 1101 roof window

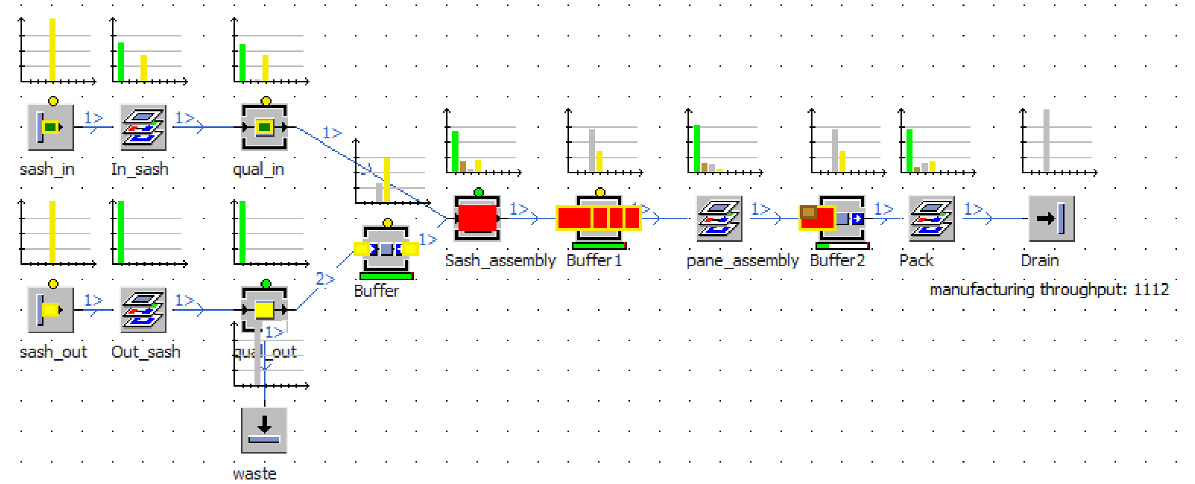



**A+E:** Case A combined with supporting operations on sash_assembly station by cobot.
**Scenario details:** Buffer capacity = 2, Buffer1 capacity = 4, Buffer2 capacity = 4, Sash_assembly: $t_i$ -> (0:30, 0:20, 0:40) $t_{su}$ -> (2:30, 1:15, 3:00)
**Total throughput** of the manufacturing system after changes: 1124 roof window

**Table 2** Summary of analysed scenarios of changes in the production system (continuation)




**A+F:** Case A combined with vision system(worker free) for sash quality (scratch, dimension, angles, colour) control.
**Scenario details:** Buffer capacity 2, Buffer1 capacity 4, Buffer2 capacity 4, Sash_assembly: $t_i$ -> (0:30, 0:20, 0:50) $t_{su}$ -> (3:30, 2:15, 4:00), Station qual_in: $t_i$ -> 0:30 Station qual_out: $t_i$ -> 0:30
**Total throughput** of the manufacturing system after changes: 1112 roof window




### 4.3 Estimating the financial impact of production system change scenarios

It is not sufficient to limit the decision-making process solely to assessing the production effects of change options. Recommending the selection of one of them requires at least taking into account the financial parameters of the scenario. In the methodology being developed, it is proposed to use throughput accounting (TA) to estimate the financial impact of the options for change being analysed. TA is a simplified management accounting method that provides managers with support in making decisions aimed at increasing the profitability of the company. The undoubted advantage of TA is simplicity in assessing the investment made through practical and simple measures that take into account the impact of the changes on the whole functioning of the company. Those that have been used in the proposed methodology are presented in Table 3.

**Table 3** TA meters used to estimate the cost-effectiveness of change scenarios

| | |
|---|---|
| Throughput = Sales Revenue – Totally Variable Cost<br>T = SR – TVC | Throughput (T) is net sales (SR) less totally variable cost (TVC), generally the cost of the raw materials, transportation charges, outsourced processing, commissions deducted for sales.<br>*Labour and energy in manufacturing organizations are usually not tied to units produced. |
| Net profit = Throughput – Operating Expense<br>NP = T – OE | Operating Expenses: Operating expenses (OE) refer to other cash outflows needed for creating the throughputs like payments made for salaries and benefits of employees, maintenance, rental expenses, lease expenses, taxes and license fees, cost of utilities, etc. |
| Return on Investment = Net Profit / Investment<br>ROI = NP / I | Investments (I) represent funds tied up in physical assets such as machinery and equipment, land and buildings, product inventory, etc. In the TOC these all referred to as inventory |

Based on: [40]

TA is designed as a direct cost approach and as such supports in particular short- and medium-term production decisions [41]. Although it does not provide such precise answers as traditional accounting, it is sufficiently accurate for tactical investment decisions. Table 4 compiles estimates of financial parameters for each production system change scenario. It is assumed that the throughput/unit is 5 €, and during the year the company work for 250 days. It should be noted that the investment costs have been estimated and are all the more precise the less innovative the solution proposed in the scenario.

The very high ROI results show that the company should decide to make investments to increase production capacity to 1100 units per day. The most cost-effective option was the introduction of three buffers to mitigate the effects of variable technological operations times and standardisation at the installation site of the inner wing and the outer window (scenario C). This solution provides for the introduction of additional bonuses for employees in this position of € 150/day, but the assumed effects in the form of a capacity increase of € 1480/day justify this expenditure. Such an increase in earnings (about 40 %) should ensure that workers with key skills are maintained over a longer period of time. The danger was that the quality would be reduced, so when implementing this solution, the company decided to make a 4h shift for each employee in this position and move it to a neighbouring position (pane assembly).

**Table 4** Financial parameters of the analysed changes in the production system

| | A | B | A + C | A + D | A + E | A + F |
|---|---|---|---|---|---|---|
| Δunits/day | 166 | 217 | 296 | 296 | 296 | 296 |
| ΔT/day (€) | 830 | 1085 | 1480 | 1480 | 1480 | 1480 |
| ΔOE (€/day) | 12.5 | 492 | 160.5 | 153.5 | 40.9 | 43.5 |
| Δdepreciation €/day | 10.5 | 8 | 10.5 | 18.5 | 32.9 | 22.5 |
| Δsalary €/day | 0 | 480 | 150 | 120 | 0 | 0 |
| Δmaintenance €/day | 2 | 2 | 0 | 10 | 4 | 15 |
| Δenergy €/day | 0 | 2 | 0 | 5 | 4 | 6 |
| ΔNP (€/day) | 817.5 | 593 | 1319.5 | 1326.5 | 1439.1 | 1436.5 |
| ΔNP (€/year) | 204375 | 148250 | 329875 | 331625 | 359775 | 359125 |
| ΔI (€) | 2625 | 2000 | 3125 | 4625 | 8225 | 5625 |
| ROI = ΔNP/ΔI | 77.86 | 74,13 | **105.56** | 71.70 | 43.74 | 63.84 |

### 4.4 Discussion

The study presented was based on a case study of a medium-sized production company. It showed the use of the proposed capacity planning methodology to answer the question of which of the available scenarios for changes that adapts capacity to demand should be implemented by the company. Analyses leading to the selection of the change plan option were carried out within a month. It should be noted that the development of the computer model of the system itself (together with the collection of data) took 2 weeks. If such a model were already available at the time of the question of the possibility of changing capacity, the response time could be reduced, or more change scenarios could be designed.

A key advantage of computer simulation approaches is the ability to deal with complex stochastic problems without the need for advanced mathematical skills [42]. The article shows how DES can easily support mid-level managers in managing the company's operations. Although it is not a precise tool, it is accurate enough to allow for rational decision-making in the case of medium-term investments. DES systems are constantly being improved. In addition, the growing offer of textbooks, tutorials, and discussion forums makes it possible to acquire competencies sufficient to model a production system in a specific enterprise relatively quickly (about a month). This task is also facilitated by access to production documentation from ERP class systems. Thus, the limitations of the availability of computer simulation tools for SMEs due to knowledge, cost, data availability and development time (limited by knowledge, cost, data availability and development time) [43] are systematically losing their importance.

The methodology proposes to design change scenarios in a predetermined sequence. Thus, plans are created with increasing complexity, which allows, among other things, for combining scenar-ios of change. This was the case, where further capacity expansion was based on the implementation of scenario A and expanding it with new elements. The initial simulations already concluded that buffers are the solution to the volatility resulting from short-term stochastic irregularities [44]. Their introduction involves the dilemma of increasing work-in-process (WIP)to fully utilize resources.

In the proposed methodology, the investment profitability analysis is evaluated based on the ROI determined according to the TA principles. The assumptions of the cost analysis TA method used proved simple to understand for the engineers implementing the project. However, this approach does not account for the uncertainty with which the costs of innovative solutions are estimated. In the case study, this applies to the scenarios labelled A+E and A+F.

The specificity of the object of the investigation lies in the fact that the company does not forecast demand itself, but rather adjusts its production capacity to the limits imposed by the central distributor. This is quite a typical situation in the case of Polish companies, which often carry out production for European brands.

The proposed methodology is adequate for enterprises implementing complex discrete production. The effectiveness of the method developed has been demonstrated by applying it in a real-life production process. The results show that using the associated DES and TA tools allow managers to successfully design scenarios of changes in the production system, analyze them and assess their financial impact. The rationalization of tactical capacity planning enables a quick response to emerging opportunities to increase revenues related to changes in demand or reduce costs by implementing new technological solutions.

It is a challenging skill that constitutes a competitive advantage in various SME enterprises with complex production systems. The use of DES software enables the design and analysis of change scenarios taking into account technical constraints. It allows the extrapolation of production capacity, providing the basis for economic assessments. The proposed approach is the foundation for planning the development of a production system that have regard both technical constraints and profit-making aspects.

## 5. Conclusions and future research

Digital models and simulation experiments make it possible to bring a lot of relevant information into the capacity planning process that is not otherwise possible in practice. The importance of DES in tactical capacity planning stems from the fact that different decision options for organising the process can be tested before they are implemented. The concept of combining DES and TA-based financial analysis is related to the need for decision support that:

- must be carried out in a relatively short and limited period of time,
- has little recourse to external consultancy, (e.g. for financial analysis),
- is not routine and may not follow a set pattern, such as the entry of overtime,
- requires a good understanding of the production situation.

Among other things, tactical capacity planning decisions are made under such conditions. The proposed methodology enables a small team of engineers to find answers to the questions: what will happen if certain changes are made [1], where their weaknesses are [2], how individual change scenarios will affect the capacity of the overall system [3]. However, it must be emphasized that the proposed methodology does not lead to an optimal decision. Nor does it guarantee to find solutions that are workable. It requires employees involved in the decision-making process to be creative in designing change scenarios and skilled in operating the computer system.

The need to support decision-making processes in terms of tactical changes in production systems is not only due to the need to match capacity to demand. It is also related to the analysis of the effects of implementing solutions that fit into the Industry 4.0 concept. Many SMEs are already facing a dilemma regarding this type of investment. The proposed methodology makes it possible to estimate the impact of changes on system capacity and seems adequate to support this type of decision as well. However, this requires verification of not only the manufacturing system but the entire production system. Research on the use of the methodology in evaluating scenarios for introducing elements of the Industry 4.0 concept in a medium-sized manufacturing company is currently being conducted. Furthermore, the subject of the research is also the introduction of multi-criteria decision - making methods for the evaluation of change scenarios in terms of sustainable development criteria resulting from the corporate strategy.

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