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A SIMULATION-BASED APPROACH FOR LINE BALANCING UNDER DEMAND UNCERTAINTY IN PRODUCTION ENVIRONMENT

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ABSTRACT

The management of the production line is a challenging task due to the high level of uncertainty in demand, which can lead to unbalanced utilization of resources. This may result in a potential deterioration of management satisfaction in terms of cost-effectiveness. Therefore, it requires efficient tools to optimize resource utilization. With such inherent needs, this paper presents a simulation-based decision support framework for garments industries. The Discrete Event Simulation (DES) is used to model different scenarios for the operational processes. The procedure focuses on the line balancing technique, which aims to eliminate bottlenecks and optimize the production process by balancing the workload. The results of this study demonstrate the effectiveness of the line balancing technique in improving line efficiency, reducing the idle time of the operators, and increasing productivity. The simulation was developed using AnyLogic simulation software. The outcome of the process is thoroughly evaluated and justified using a case study.

1 INTRODUCTION

The fast-changing consumer demand, international rivalry, the complexity of the supply chain, and environmental concerns are just a few of the production issues that the ready-made garment (RMG) industries must overcome. Rapid production cycles are needed to meet consumer demand for new fashions and trends, which puts pressure on producers to lower prices and shorten lead times. Prices are lowered by global competition, that imposes pressure on businesses to increase productivity and efficiency. It is challenging to monitor and regulate quality in complex supply chains with numerous suppliers and stakeholders, which results in production delays and increased prices.

In these circumstances, line balancing is a crucial step in the garment industry for increasing production efficiency and lowering costs. It is the process of allocating the proper number of workers to each task on a production line to prevent bottlenecks and delays. Manufacturers can boost output, cut down on lead times, and enhance quality control by balancing the line. The optimal use of resources, equipment, and labor makes resource optimization essential in the clothing industry. Manufacturers may decrease waste, enhance product quality, and boost profitability by optimizing their resource use. Hence, it is impossible to overestimate the significance of line balancing and resource efficiency in the clothing sector. To sustain in a highly competitive market, producers need to be able to produce high-quality goods swiftly and affordably. Manufacturers can attain these objectives and boost their bottom line by managing production

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lines and utilizing resources to their fullest potential. Furthermore, customers and other stakeholders are placing an increasing amount of value on resource efficiency and sustainability, thus it is crucial for manufacturers to give these practices top priority to preserve their reputation and market position for their business.

In the industrial sector, particularly in the ready-made garment industries, where production efficiency and cost-effectiveness are critical, the idea of line balancing has grown in significance. By ensuring that every workstation in the assembly line is used to its full ability and minimizing downtime and bottlenecks, line balancing aims to optimize production operations. This project will investigate the use of AnyLogic simulation software to enhance line balancing in the ready-made clothing sector. Due to the quick changes in fashion, the configuration of the line must be updated regularly in the garment industry. To successfully complete the line balancing operation, a comprehensive inspection of the entire system is required. But it is quite difficult for a human to analyze actual production systems because of the fast overall process development, the larger quantity of system variables, and as these components are stochastic. Also, it is quite difficult to manually fix line balance problems while considering all the variables that may affect the overall system's performance. Several studies have been conducted to improve the production efficiency of the ready-made garments industry as well.

Discrete event simulation (DES) is an effective tool for garments line simulation. Different writers tried to solve problems in different manners. Güner et al. (2008) discussed how the simulation model helps managers to prevent unexpected situations. An integrated simulation model is created that generates a set of optimal production alternatives as well as a set of optimizing alternatives for a heavy continuous rolling mill system in a real steel industry, Azadeh (2000). Besides that, Patel (2002) talked about the modeling and research methods used to analyze the Final Process System of the vehicle manufacturing process and create a productive and effective procedure to guarantee the system throughput. They have focused on Process Layout, Testing station, and Repair stations where operators have the most impact on system output. Choi et al. (2002) explained the first steps taken to deploy simulation modeling as a visual management and analysis tool at a company that makes engine blocks for automobiles. A recent study was observed in the related field by Halie et al. (2018) who outlined a simulation technique in an apparel industry by using Arena software. For line balancing techniques, Talapatra et al. (2018) discussed how production efficiency can be improved using Yamazumi Chart. The RMG sector must maintain the warehouse system on their premises, and it incurs huge costs for supply chain works. Mustofa (2020) tried to interpret how the bullwhip effect affects the performance of an industry. Through this analysis discussed in the cement industry, Rahman and Shohan (2015) showed an approach to explain how cost evaluation affects factory performance in terms of supplier selection which can be used to minimize cost factors in the RMG industry. Sultana et al (2014) also explained how cost evaluation affects factory performance in terms of supplier selection in two different processes and this cost comparison has a significant impact on the total raw material cost of the finished products.

In this paper, the author gave an idea regarding risk identification for different processes using a fuzzy approach which can be used for cost minimization in industry, and imaging process can help a lot in future improvement (Rabbi 2018). Saeheaw et al. (2009) emphasized the use of Arena simulation software in a hard disk drive production process in which average time and waiting time has decreased by a great amount. Since the RMG industry has no automotive and manual handling is mandatory here. Junga et al. (2022) presented a method for simulating a manufacturing line that uses data from real-time power monitoring, specifically the individual task periods of the workers who make clothes. Using ICT-based power monitoring devices, power consumption data for sewing machines used by workers are gathered. The data is then sent over a wireless network to a cloud server where they are analyzed by an approximation algorithm to determine the precise job time. An ICT-based PMS was developed and deployed to collect the power profile data generated by the sewing machines on a garment production line, and an individual worker's task time was extracted by processing the collected power monitoring data through a pattern analysis algorithm. Another study found by Unal et al. (2009), proposed a heuristic algorithm for line balancing and to simulate the algorithm's performance under various line configurations. Gurkan (2005) interpreted how to provide weaving mills with ideas for organizing themselves more effectively and estimating when their orders will be delivered using simulation techniques.

Ali et al. (2005) analyzed the performance of a combination of product mix and production volume under different scenarios using reconfigurable assembly system modeling through the Arena simulation software. Cycle time is an important factor for line balancing and Kibira et al. (2002) optimized the different task issues such as line balancing, cycle time reduction, and material handling work using a discrete event simulation model at which the effort and level of task during the simulation also pointed out. Moreover, a relevant production work was presented in which Patel (2002) used a discrete event simulation model to analyze the issues to ensure the development of efficient and effective processes that secures the system throughput. Roy et al. (2021) interpreted face recognition during covid situation which is valuable for worker health analysis during covid period. Potoradi et al. (2002) maximized the demand fulfillment in which the simulation engine is used to schedule generation subject to system requirements and to control the machine execution time. In this digital age, the industry requires a modern approach to visualize capacity study with line feeding techniques for which Kamal et al. (2019) implemented an android system in warehouses of the production line which can be the future study of this paper to make the model more advanced. Ergonomic factors will be considered in the future research of this case study because the ergonomics factor of an operator can contribute a lot to make more line production (Pervez et al. 2022). The most ancient but remarkable specialist named Balci (1989) directs the simulation experts through the life cycle's 10 procedures, 10 phases, and 13 stages of credibility assessment. The guidelines help simulation practitioners with issue formulation, solution technique investigation, a system under study investigation, simulation model formulation, representation, and programming, design of experiments, experimentation, and model redefinition. Parvez et al. (2017) balance the line for the garments industry using the work sharing method. They use a conventional layout system but not any simulation procedure.

The solution approach began by identifying the critical process of the production process and outlining the parameters of line balancing. The disadvantages of conventional line balancing techniques are then covered, along with the benefits of employing simulation software instead. Then, AnyLogic simulation software is presented as a production line modeling and simulation tool. The case study is centered on a fictitious T-shirt manufacturer. Many workstations, such as cutting, sewing, and packing stations, make up the production line. To ensure that each workstation runs at its optimal efficiency, the production process must be optimized. This study will examine several scenarios and methods for balancing the line, such as changing the number of employees, workstations, and output rate. The simulation model is created using AnyLogic simulation software, a powerful tool for modeling and assessing complicated systems. Users of AnyLogic can model and simulate a variety of scenarios, from transportation networks to manufacturing processes, using the software's user-friendly interface. We can pinpoint possible bottlenecks and streamline the production process to boost output and cut costs by simulating various situations. A thorough report containing visualizations of the production line, throughput, and efficiency will be the project's final deliverable. Based on the results of the simulation, the report will also offer suggestions for enhancing line balancing in the ready-to-wear business.

The report then goes on to detail the approach taken to increase the case company's production efficiency. The bottleneck processes were initially determined by the authors' analysis of the current production line. Afterwards, they modeled the production line and tested several line balancing situations using the AnyLogic simulation software. The production line was optimized using the simulation data, and worker and machine downtime was decreased. The results of the study show that the use of AnyLogic simulation software can significantly improve the production efficiency of ready-made garment industries. Overall, this project aims to demonstrate the benefits of using simulation software for line balancing in the manufacturing industry. By optimizing production processes, companies can improve efficiency, reduce costs, and ultimately provide better quality products to their customers.

2 PROBLEM STATEMENT

The production line RMG industries are subject to change frequently within a short period of time. Changes in production layout, adding or removing machines, new operators assigning are common scenarios in RMG production lines. There are many reasons that these scenarios cannot be standardized such as uncertain demand surge or recede due to the seasonal effect, changes in product style, new buyers on board, etc. Since the buyer place orders of different styles of product at different industries based on the company's floor capacity, the production authority often faces challenges to meet this aggregate demand within a limited amount of time to get the buyer's order. However, the management must fulfill the production target and meet the buyer's and market needs. Of course, adding additional resources can ease the task, but the management also considers the subsequent impact and cost effectiveness. At the same time managers should have maintain line efficiency since there is a cost factor for every change in the production line. So, the managers must come up with a responsive plan to fulfill the order and to maintain line efficiency through appropriate changes such as allocation of machines, operators, working hours, etc. To do so, managers often face challenges since they have a very limited idea of balancing a production line in a new set-up, especially for a new style of product when there is no historical data. Moreover, the time constraints make the situation more critical. In such a scenario, usually, the management relies on previous experience and applies the trial-error approach to adjust the production line and achieve the desired efficiency level.

Obviously, this approach is very subjective, requires high level experience, and time-consuming resulting in an unnecessary waste of time and resources. But with recent advancement of technology and computation power, simulation can play a critical role in improving the situation. The application of computer simulation enables us to perform experiments, adjust resources, understand its impacts, and make a comprehensive plan. All of these can be done in digital platform without any allocation of physical resources and waste of time. Thus, the simulation approach can help the managers to experiment with all the scenarios, making a comprehensive plan ached of time and later implement them with confidence in the physical production line. Hence, we demonstrate the simulation-based approach, where the managers can experiment and take the effective decision before implementing in actual production environment. Thus, it helps to make informed decisions and handle the challenges in production line settings. In this case study, we used the Any Logic simulation software to experiment with five different scenarios.

3 CASE STUDY & DATA COLLECTION

This is the case study in RMG sector in Bangladesh where the Garments industry deals with various garments including T-shirts, Shirts, trousers, jeans, and other ready-made products. The primary objective of the study is to fulfill the buyers' targets, which entails producing the appropriate amount of goods within the allotted time frame and adhering to certain quality requirements. This study emphasizes the time pressures that the apparel business faces in meeting consumer needs. Time constraints can vary depending on factors such as order size, lead time agreements with buyers, and the complexity of the products. The case study covers the issue of demand ambiguity, which is a common problem in the apparel sector. Demand uncertainty might develop because of shifting market trends, shifting customer preferences, seasonal variations, or unanticipated occurrences that affect consumer demand. A simulation model enables comparing various line balancing tactics and determining the most effective configuration by capturing the dynamics of the production process and including demand unpredictability.

Here the author considers a basic T-shirt for the simulation-based approach for this case study. This case study is performed based on the data collected from a reputed Garments industry in Bangladesh. The data is collected for a specific style of T-shirt which is produced in thirteen steps at thirteen different workstations. The production line starts with a shoulder joint operation, where one operation combines the shoulder part with the neck joint operation. The finished item is subsequently moved to the following workstation, where the Rib tack operation is completed. The outputs of one workstation are sent to the succeeding workstation for the following process as this series continues. For reference, a flowchart of the production process is shown in Figure 1. In this study, the Triangular distribution is used to model the operation time at each workstation of the production line. The triangular distribution consists of the three parameters a, b, and c for minimum, maximum, and mode values, respectively.

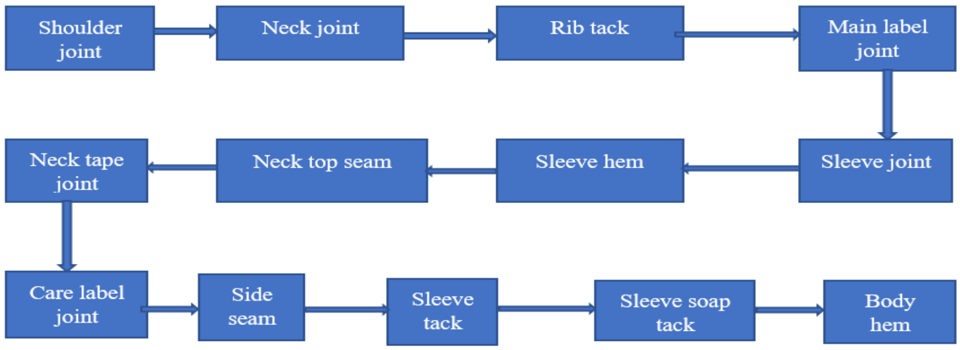

Figure 1: Production flow chart of a basic T-shirt production.

This strategy was chosen to take into consideration the fluctuating capacity of garment operators, which varies from the beginning of production through the learning curve. Usually, the operators can complete an operation within a certain average time. However, in some cases it may take longer time than usual, especially in the event of some random occurrence such as part adjusting, machine malfunctioning, absence of helping hand, or others. On the other hand, sometimes operators can complete their tasks in the minimum possible time in favorable working conditions. Hence, the assumption of triangular distribution is appropriate in this scenario. In particular, the operators' most frequent workload has been represented by the mode value of the triangular distribution, while the performance range of variability has been captured by the minimum and maximum values. Utilizing the triangular distribution in this situation offers a flexible and efficient way to simulate the manufacturing process and account for the operators' fluctuating capability. Here, Table 1 shows the standard capacity of different process operators with the triangular distribution.

Table 1: Capacity and process time at each workstation.

S/L	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Process Name	**Shoulder joint**	**Neck joint**	**Rib tack**	**Main label joint**	**Neck tape joint**	**Neck top seam**	**Sleeve hem**	**Sleeve joint**	**Care label joint**	**Side seam**	**Sleeve tack**	**Sleeve soap tack**	**Body hem**
Capacity Pcs/Hr.	300	120	180	250	120	130	90	120	300	130	350	300	110
Min	3	2	2	2	1	2	1	2	3	1	4	2	2
Max	6	3	5	5	3	4	4	3	6	4	7	3	3
Mode	5	2	3	4	2	2	2	2	5	2	6	5	2

4 SCENARIOS & MODEL DESCRIPTION

In this case study, the production manager needs to produce 1600 T-shirts per day in the peak season of summer. Also, in the other season, they need to maintain their line efficiency with optimum operator cost and utilization. During the peak season, the production demand is very high, while in the off-season the production requirements drop significantly. The task of handling such opposite production scenarios is not trivial but rather requires informed decision-making strategies. Hence, we describe five different scenarios to show the systematic approach to improve the management decision.

Scenario 1: In this Case study the author tries to mitigate the problem of line balancing at the factory premises using AnyLogic simulation before the setting up of the line practically. Hence, we have designed a scenario assuming a general layout of the production line. To model this scenario, we first develop a simulation with a standard set-up of production line where eleven operators work at thirteen workstations. This model entails eleven operators operating at thirteen separate workstations as shown in Figure 2.

Once the model was developed, we proceeded to run simulations based on a standard workday of eight operating hours. According to the results obtained from this standardized setup, the line efficiency was found to be 93% without any significant bottleneck in the production line. However, we observed that the operators' utilization was remarkably low. Consequently, the existing line fell short of meeting the target output of 1600 pieces. The production line can produce 919 pieces at its maximum capacity. Hence, the simulation of the production line runs at high line efficiency but demonstrates significant issues with operator utilization. Also, in this scenario, due to the missing amount of 681 pieces from the shipment will make a penalty cost from the shipment. Consequently, the current system failed to achieve the desired production output, falling considerably short of the target.

Scenario 2. Since the target output was not obtained as desired from Scenario 1, the authority needs to decide whether to add operators or allocate overtime to fulfill the production target. The decision is driven by some other factors such as availability of operators on demand, hiring and/or lay-off cost, etc. In the country where this case study took place, it is comparatively easy to hire operators when there is a need for excessive production, especially in the peak season. However, the authority also should consider that these additional operators will be a burden in the off-season due to the fact of low demand and operators will remain underutilized. It will result in overall production inefficiency or excessive lay-off cost. Hence, it is more appropriate to allow overtime in the peak season, instead of hiring additional operators. The cost-effectiveness of overtime allocation is explained in Section 5. Hence, it is crucial to decide the number of overtime hours required to meet the target. To identify this, we develop a simulation model with the existing 11 operators to determine the number of hours it takes to complete the production of 1600 pieces of T-shirt. In this case, it is observed that the production target can be fulfilled in 13 hours with a line efficiency of 94%. It indicates that the management needs to allocate 5 hours of overtime for the 11 operators to get the desired output.

Scenario 3. Clearly, the second scenario (refer to Figure 3-a) shows an unbalanced utilization at different workstations, though the desired production target is achieved with a reasonable efficiency of 94% is achieved in Scenario 2. Such unbalanced utilization may result in an unacceptable situation, where some operators are overburdened while others are underutilized with less workload. It may result in worker unsatisfaction, violate industry compliances, deteriorate safety issues, and more importantly it may impact overall product quality. Hence, we have tried to balance the utilization of the operators from the above-mentioned scenario (Scenario-2, Figure 3-a). To do so, we set the task priority (the operator with high skill will help the next workstations after completing the task of the primary workstations) between two processes named Sleeve tack and Neck tape seam. But it is observed that with the running time of the standard 8 hrs., the output is low, which is only 1031 pcs with an efficiency of only 61% (Scenario 2, Figure 3-b). Hence there are 569 pieces of missing garments from the shipment amount which will make a penalty cost from the shipment value.

Scenario 4. Since no noticeable improvement is observed for efficiency in Scenario 3, we modify the simulation with the two merged processes which means 10 operators (Sleeve tack and Neck tape seam process carried out by single operator) for 1600 pcs output, but it took a significant amount of time more than 20 hrs. with several bottlenecks in the process.

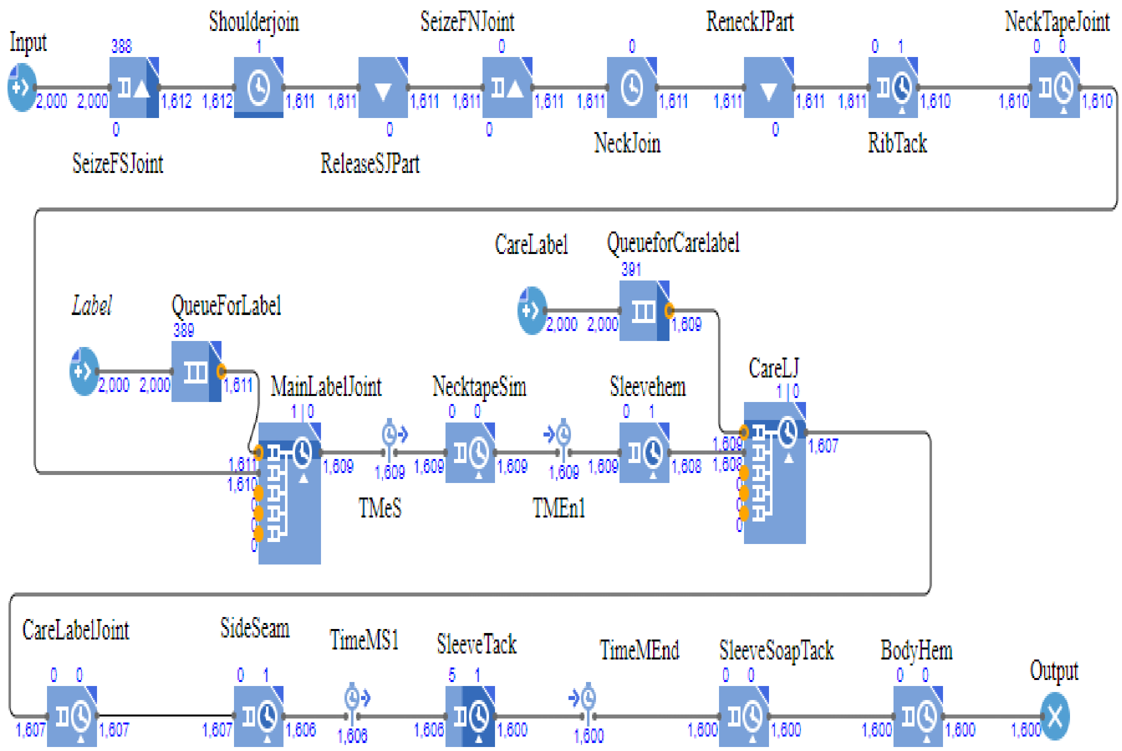

Figure 2: AnyLogic simulation model for the process flow of the production line.

Due to the shortage of 1 operator the output of the other workstations has been decreased, which creates a bottleneck in the process. From this experiment, we can see that reducing one operator from the line makes the whole system become infeasible because in that case more operating hours are needed (also, other operators become overburdened) due to the shortage of one operator who would help them in several ways during production say a little relaxation time when working) for the desired output and the efficiency is significantly lower. This still results in underutilization of operators, which means the line is still unbalanced, which can be observed in Figure 3-b. Hence the operator utilization problem has not yet been solved for the desired line output with efficiency.

Scenario 5. To tackle the previously mentioned issue in Scenario 4, the author conducts a thorough examination of the production line, specifically focusing on various workstations. The findings revealed that by merging two processes side by side and assigning a single operator (in the other two processes named sleeve tack and sleeve soap tack rather than it was Sleeve tack and Neck tape seam in Scenario 4 to handle both, the desired output can be achieved with a reduced workforce of only 10 operators. This innovative arrangement not only optimizes operator utilization but also enhances efficiency, as illustrated in Figure 3-c. The implementation of this streamlined setup allows for seamless coordination between the two processes, eliminating any potential bottlenecks and ensuring a smooth workflow.

By consolidating tasks and empowering operators to handle multiple responsibilities, the production line operates with greater effectiveness, leading to improved productivity and resource allocation. This approach effectively tackles the challenges presented in Scenario 4 from Figure 3-b while offering a practical solution that optimizes both manpower and output quality.

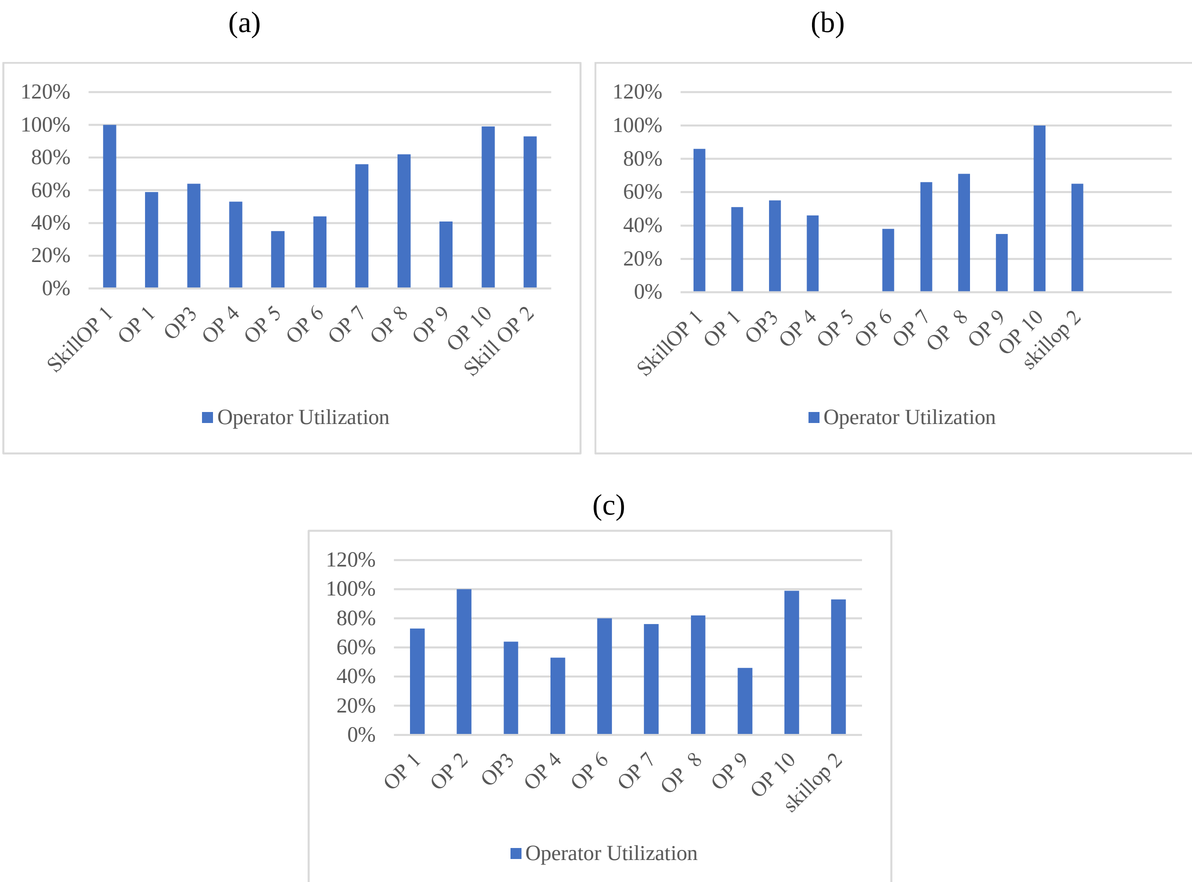

Figure 3: Utilization of Operators. (a) Scenarios 1 and 2, (b) Scenarios 3 and 4, (c) Scenario 5.

5 RESULTS & ANALYSIS

Since each of the above scenarios has a specific outcome in terms of efficiency, output, and operator utilization, the author tries to consider that different scenarios for operators' utilization and efficiency consideration with the desired output throughout the year for the company's profit margin. The outcome of each of the scenarios was evaluated based on the number of operators utilized, operating minutes (based on the standard working and overtime hour) to generate the output, SMV, line output, and line efficiency in Equation (1).

$$E = (G * SMV)/(T * 100) \qquad (1)$$

where G denotes total produced garments and T denotes total hours worked, the SMV (standard minutes value, SMV = Basic Time + Allowances) is calculated using time study and motion study of the operators. So, from the above discussed five scenarios, the best scenario of this case study is the fifth scenario for the peak season with 1600 pcs output per day. Table 2 shows all the scenarios with different outcomes:

Table 2: Evaluation metrics for different scenarios.

Scenarios	No. Of Operators	Operating Minutes	SMV	Line Output	Line Efficiency	Missing Amount
Scenario-1	11	5280	5.39	919	93.81%	681
Scenario-2	11	9126		1600	94.50%	0
Scenario-3	10	9100		1031	61.07%	569
Scenario-4	10	13100		1600	65.83%	0
Scenario-5	10	9146		1600	94.29%	0

Note that we have considered different operating minutes because during the off-season the line must run on a standard 8-hr basis to maintain efficiency as demand is comparatively less during this time. According to expert surveys and based on historical data, working overtime provides additional rewards that significantly increase employee motivation. Additionally, the company gains from the reduced operator presence because the fixed expenses are reduced. Therefore, it is advised to run the line with an optimal amount of overtime, especially during the peak season. Thus, the industries avoid additional payments to the extra operator throughout the year. Figure 4-a shows the efficiency of five different scenarios discussed above based on the requirements. In addition, we demonstrate the cost incurred for each scenario. The total cost depends on the operator's standard (regular hour) salary, overtime cost, and penalty cost as shown in Equation (2).

$$Y = B \times E + (M \times O) + P \tag{2}$$

where B is the Basic salary, E represents the number of operators in the production line, M indicates the overtime salary rate (Usually double of basic), O denotes the overtime hours, and P defines the penalty cost for losing the target amount. Usually, the overtime salary is double the regular hour salary. The penalty cost is directly related to the daily production target. Any amount below the production target is considered as a penalty and thus related to the penalty cost. In this case study, such penalty cost is added for Scenario 1 and Scenario 3 resulting in the highest cost as is shown in Figure 4-b.

(a) (b)

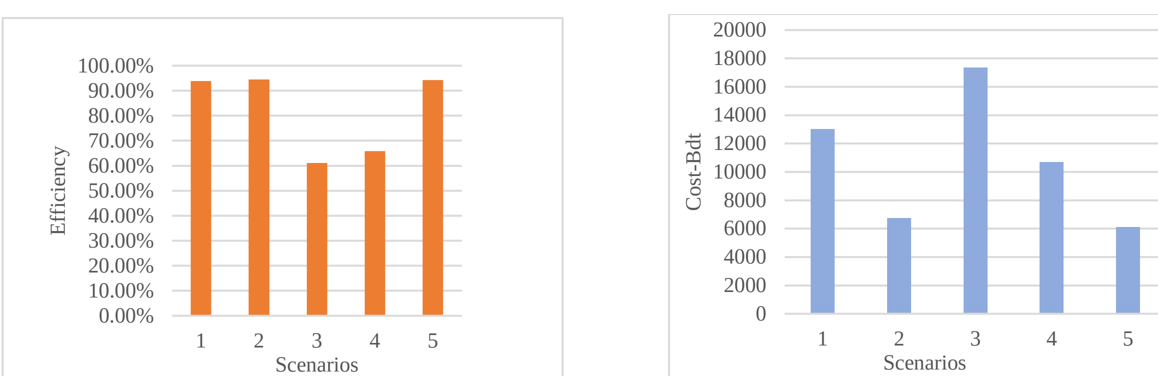

Figure 4: (a) Efficiency variation. (b) Cost comparison per day.

6 DISCUSSION & CONCLUSION

This paper demonstrates a simulation-based approach to managing the line balancing problem in RMG sectors. Using such an approach, a manager can obtain critical insights for any production process, such as testing a new system before implementation, information gaining without modifying the actual system, labor requirements planning, and process improvement. Usually, process managers rely on their experiences and/or traditional approaches for production planning, which sometimes lack proper justification and validation. Whereas the simulation approach provides an informed decision by running the production line in a digital platform and generates reliable decision-making outcomes. Regarding the assessment of the behavior of the line and line balancing, the proposed approach can readily be used. In this way, any unexpected situations can be prevented if a manager uses simulation model-based analysis. In today's competitive era, industries must respond rapidly to sustain and capture the market. In such cases, it is indispensable to know about the current situation of the system to process the orders timely since it involves high costs and Changeover time. For this reason, it is possible to forecast short-term and long-term effects and boost productivity by creating a simulation model which is unparallel to a real-world system.

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