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RESEARCH ARTICLE

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A complex garment assembly line balancing using simulation-based optimization

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Abstract

The nascent wave of disruptive competition in the current business environment brought about by the fourth industrial revolution (Fashion 4.0 or Apparel 4.0) is enormous. Therefore, it is important for the apparel industry to be flexible enough to respond quickly to the unstable customers' demand through continuous improvement of their process efficiency and productivity. This study proposed assembly line balancing problem (ALBP) for complex garment assembly line using simulation-based optimization under stochastic task times. The proposed ALBP solution approach aimed at minimizing the cycle time for a given number of workstations with consideration of constraints on number of resources, precedence relations, and resource types. The empirical study was conducted at Southern Range Nyanza Limited (NYTIL) garment facility and a complex trouser assembly line with 69 workstations was considered. The discrete event simulation of the trouser assembly line was developed using Arena simulation software. The local optimal solution was obtained from simulation experiments which was adopted for the optimization process. The OptQuest tool was used to solve a single objective optimization with discrete control values. The results showed that the average throughput increased by 30% for local optimal line balancing and 55% for global optimal line balancing. Consequently, the cycle time reduced by 23% and 36%, respectively.

KEYWORDS

assembly line balancing, Arena software, discrete event simulation, OptQuest optimization, simulation modeling

1 | INTRODUCTION

The engineering marvels imputed by Fordism and Taylorism in the early age of the second industrial revolution led to the advent of assembly line. It is unprecedented and often credited as one of the most significant development of production systems in the modern world.[1] An assembly line consists of a set of workstations where a set of operations are carried out with the aim of obtaining the final product.[2] In assembly line, tasks are allocated to the workstations considering some restrictions including precedence constraints, cycle time, and the number of workstations, and thus increasing its complexity.[3] However, assembly lines are used extensively in mass production systems to produce high quantity standardized products.[4] For this reason, assembly line balancing becomes very crucial for proper functioning of the assembly line system.

The balancing of assembly lines is an important issue in manufacturing engineering, management, and control.[5-7] However, assembly line balancing is a very complex phenomenon which has been dubbed as a nondeterministic polynomial (NP) hard problem or complex combinatorial problem.[8,9] Despite the fact that research on assembly line balancing dates back to more than a century, it is still of interest to many researchers. This is because assembly line balancing problem (ALBP) is directly related to production efficiency.[10] Hence, the advancement and search for more efficient and effective assembly line balancing approach is emblematic for improving production efficiency and sustainability of the production process.

Simulation-based optimization (SBO) is the state-of-the-art design technique that combines both simulation and optimization techniques.[11] The application and development of this method is increasing drastically as it is one of the key disruptive technologies shaping the era of the fourth industrial revolution (industry 4.0).[12] The apparel industries are the late-comers adopting disruptive technologies. Recently, the term Fashion 4.0 or Apparel 4.0 has been coined as the analogy to industry 4.0 to reflect the adoption of disruptive technologies in apparel and textiles industries with the emphasis on increasing sustainability and competitiveness in this sector.[13]

Previously, researchers dealt with assembly line balancing using simulation and optimization methods but independently. Since the advent of computer technology, simulation has been used in various fields including manufacturing, healthcare, marketing, transportation, and supply chain. Of these, manufacturing systems emerged to be the most important area in which simulation has been successfully adopted.[14] However, most practical manufacturing systems are extremely complex that finding optimal decision variables analytically are extremely difficult. Therefore, SBO is widely used in evaluating complex systems, and optimizing responses for manufacturing problems.[15]

The distinctive hurdles for garment manufacturers are long production lead time, bottlenecking, and low productivity. Moreover, sewing or assembly line is the most critical phenomenon of garment manufacturing as it generally composes of huge number of operations and resources.[16] With the new paradigm shift in mass customization, the traditional garment production model needs to be optimized to have a more sustainable structure in order to meet demand for flexibility, low-cost, and high-efficiency.[17] The present article is based on an empirical study conducted at Southern Range Nyanza Limited (NYTIL) garment facility which regularly receive orders in large quantities and thus has imposed constant pressure to meet the demands of customers, but the existing line balancing condition is inferior and ineffective for achieving the line production target, even if the operators were to undergo forced overtime. Therefore, this article proposed a complex garment assembly line balancing using SBO and it is organized as follows; Section 2 briefly provide the relevant literature on the study, while Section 3 describes the methodology of the study. Finally, Section 4 presents the results and discussions of the study.

2 | LITERATURE REVIEW

2.1 | Assembly line balancing

Assembly line balancing, also known as assembly line design, is a family of combinatorial optimization problems that has been widely studied in literature due to its simplicity and industrial applicability.[9] ALBP is a NP-hard as it subsume the bin packing problem as a special case.[18] ALBPs arise whenever an assembly line is configured, redesigned, or adjusted. It consists of distributing the total workload for manufacturing any unit of the products to be assembled among the workstations along the line subject to a strict or average cycle time.[19] The general principal of line balancing are (1) industrial environments for which the line balancing problems considered are machining, assembly, disassembly; (2) number of product models: single-model lines, mixed-model lines, multimodel lines; (3) line layout: basic straight line, straight lines with multiple workplaces, U-shaped lines, lines with circular transfer.[20]

The ALBP was coined in 1955 by Salveson and this problem has since been studied under different situations using various methods with several classifications to make better decisions in real-life situations.[21,22] In general, there are two main types of ALBP: (1) simple assembly line balancing problems (SALBPs) in which assembly lines are arranged as serial lines in a sequential pattern with all input parameters, without considering uncertainty[23,24]; (2) generalized assembly line balancing problems which include all issues not addressed in SALBPs and display more constraints than SALBPs.[25] In the recent years, the extensions of ALBP have been conducted by researchers including mixed-model ALBP,[26,27] stochastic assembly line balancing with learning effects,[28] type-1 U-shaped assembly line balancing under uncertain task time,[29] two-sided ALBP,[30] reconfigurable transfer line balancing problem,[31] robotic ALBP,[32] robust ALBPs,[33] simple type-1 ALBPs,[34] flexible multimanned ALBP,[35] cost-oriented resource-constrained multimodel ALBP,[36] multimanned ALPB with skilled workers,[37] and disassembly line balancing problem.[38]

Published literature shows that the scope of the ALBP in research is indeed quite clear, with well-defined sets of assumptions, parameters, and objective functions. However, these borders are frequently transgressed in real-life situations, in particular for complex assembly line systems like most garment manufacturing. Therefore, applied line balancing problems which has been derived from GABLP are most suitable for such systems.[39] The applied line balancing problems in garment manufacturing evolved because garment assembly line poses unique balancing problems to those of large body assembly lines such as trucks, buses, aircraft, and machines.[40,41]

In most studies, garment assembly line balancing has been implemented using several techniques including ranked positional weight,[42] COMSOAL,[43] largest candidate rule,[44] and simulation.[41] As the complexity of garment assembly line increases depending on the fashion styles, most of these methods become less effective and inferior for line balancing .[42] This has pointed out the need for effective and efficient method for balancing complex garment assembly lines. Several studies on garment assembly line balancing based on simulation technique have been reported. For instance, Hanan and Seedahmed[45] employed MySQL Data Base Management System, Java language, Hyper Text Markup Language, Cascades Style Sheets, and SMARTY J for balancing U3 shirt assembly line. A study by Xu et al,[46] comprehensively evaluated the garment assembly using Anylogic simulation software and proved that there is need for optimization because simulation technique is only descriptive and does not help in decision making. Optimization in assembly line balancing has also gained the attention of researchers although it suffers from a number of limitations. This is normally common for manual or semiautomatic systems like most apparel industries, as it is impossible to gain certain results with metaheuristics algorithms when the assembly line is redesigned. Chen et al,[47] for example, conducted a study on grouping genetic algorithm to solve ALBP with different labor skill levels in sewing lines of garment industry. Furthermore, Dinh et al[48] applied greedy strategy to find an initial solution, followed by simulated annealing to find the best solutions for the garment ALBP. While Xu et al[49] applied an adaptive ant colony algorithm with modifications made on the traditional ant colony algorithm for solving the ALBPs. In this respect, to gain both advantages and overcome the limitation of using either simulation or optimization techniques singly, SBO is central.

2.2 | Simulation-based optimization

SBO is also known as simulation optimization, black box optimization, parametric optimization, stochastic optimization, or optimization via simulation.[50] It is a design approach that can be used to generate a number of scenarios from a probabilistic or deterministic model and then select the best alternative solution by applying scheduling decisions and aggressive search approaches to these scenarios to obtain the best solution.[11] SBO is a combination or integration of simulation and optimization/metaheuristic techniques.

The inherent complexity of assembly line and large number of feasible design alternatives make it extremely difficult to identify a global best solution with only simulation technique.[51,52] For this reason, integrating simulation with optimization means that all the advantages of the two design techniques can be harnessed. Tout ensemble, SBO has been used to solve a number of industrial engineering problems.[53]

Many researchers have improved the performance of a number of systems using SBO. Dang and Phan,[7] for example, designed an assembly line for footwear production using simulation-based adaptive large neighborhood search heuristic. Juan[54] conducted a study on production planning in manufacturing industry using SBO. A study by Yegul et al[55] also improved the configuration of the production line using SBO. Alvandi et al[56] proposed an integrated simulation-optimization framework based on metaheuristic method to overcome an inherited complexity of classical production planning in multiproduct/multimachine production systems and optimized several production objectives simultaneously. To some extent, SBO has been applied beyond the manufacturing sector and thus covering transport, agriculture, defense, and healthcare. For instance, Ibrahim et al[57] conducted a study on minimization of patient waiting time in emergency department of a public hospital using SBO approach. While, Shakibayifar et al[58] applied SBO technique to rescheduling train traffic in uncertain conditions during disruptions. Masoud et al[59] demonstrated the applicability of SBO in agriculture (horticultural nurseries).

So far, various methods and tools or techniques for SBO have been developed or used. For instance, Leung and Lau[14] applied a multiobjective SBO framework consisting of a hybrid immune-inspired algorithm named suppression-controlled multiobjective immune algorithm and a simulation model for solving a real-life multiobjective optimization problem. Yegul et al[55] optimized production line configuration, and proposed several SBO approaches based on myopic search, ant-colony, simulated annealing, and response-surface methodologies (RSM). González-Reséndiz et al[60] applied simulation and RSM in optimizing logistics process for electronic goods. Jerbi et al[61] reported that Arena/OptQuest optimization platform outperforms the Taguchi optimization method. Chiadamrong and Piyathanavong[62] used OptQuest and Arena to search for the optimal supply chain network decisions under three levels of uncertainty. Similarly, Elnaggar[63] used Arena and OptQuest to determine the best number of workstations in garment assembly line. Furthermore, Borodin et al[64] demonstrated the possibility of integrating Arena and CPLEX software tools for SBO.

Evidence from previous studies indicates that an integral of Arena and OptQuest are the most used SBO software tools.[65] However, in any design problem, selection of the software to be used for simulation is very important. It is majorly based on a number of criteria including the ease of use, animation capability, model development, and input category.[66]

To the best of our knowledge, no literature was found to have used SBO with stochastic task times and bundles processing for balancing garment assembly line. Therefore, this article is the first to propose a complex garment ALBP using SBO with consideration of stochastic task times and bundles processing. Arena/OptQuest SBO tool was selected based on the mentioned criteria with the first priority being the "ease of use" followed by "model development and input category" and then "animation capability."

3 | METHODOLOGY

This article adopted a combined discrete event simulation and optimization study approach.[67,68] This approach was applied to solve the ALBP in apparel industry with the objective to minimize the cycle time while maintaining constant number of workstations with consideration of constraints on number of resources, precedence relations, and resource types. The present study was conducted systematically following several steps (system definition, conceptual construction, modeling of inputs, construction of simulation model, verification and validation, design scenarios generation, optimization model development) as schematized by Figure 1. All these steps have been described in the following subsections 3.1 to 3.5. The data collection approach was through empirical study in which industrial engineering tools: time study, process mapping, observations, and brainstorming were used.

3.1 | System definition and conceptual modeling

NYTIL garment facility uses progressive bundle apparel production system which is normally referred to as conventional apparel production system. The operation in this system involves moving bundles of cut pieces (5, 10, 20, 25, 30, or 40 pieces) manually to feed the line. Whereby, the operator or helper inside the line drags the bundles by him/herself from the table and transfer the bundle to the next operator after completing his/her task.[69] By observation and brainstorming four categories of people: operators, quality personnel, maintenance personnel, and line supervisors, the current state of trouser assembly line (Figure 2) was defined. The line operates on 8 hours daily production shift. The trouser style consists of 72 operations performed in 69 workstations and utilizes a total of 187 resources. The resource types include operators (83), machines (83), helpers (19), and quality personnel (2). The line production target is 800 pieces per day and the average throughput of 490 pieces per day with the cycle time of 0.98 minutes. Currently, the trouser assembly line uses bundle size of 25 cut pieces. The trouser style considered in this study is named as digital camouflage mainly used by Army soldiers and police forces.

The conceptual model of trouser assembly line was developed using process mapping technique. Conceptual model is simply a series of logical relationships relative to the components (a-q trouser parts) and structure of trouser assembly line as depicted in Figure 3. This involved mapping all the processes and tasks or operations (1-72) assigned to 69 workstations. The line was divided into 11 sections or subassembly processes including front preparation (FP) for making both right and left trouser front (TF) leg (1-5 and 9-14), back preparation (BP) for assembling both right and left trouser back (TB) leg (15 and 17-19, 25-27), side pocket preparation (SPP) for stitching both left and right side pockets (6-8), back patch preparation (BPP) for making both left and right back patch (16), hip flap preparation (HFP) for preparing both left and

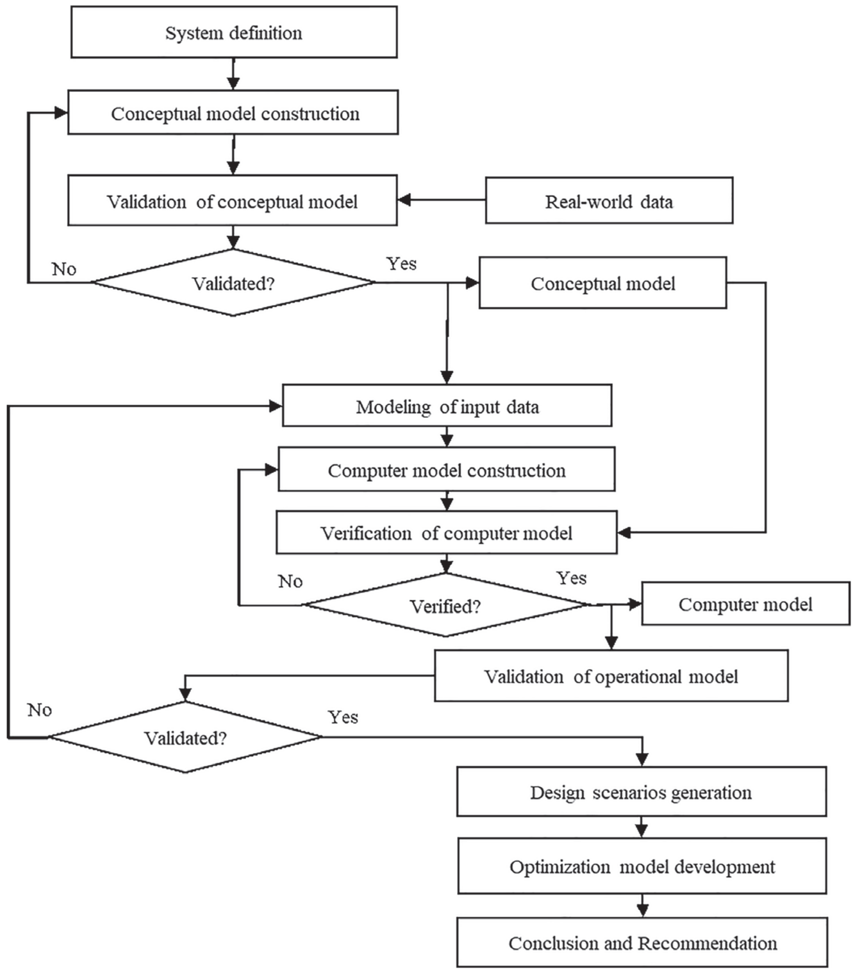

FIGURE 1 Methodology approach for this study

FIGURE 2 The NYTIL trouser assembly line

right hip pocket (20-24), knee pocket preparation (KPP) for making both left and right knee pocket (32-36), knee flap preparation (KFP) for making both left and right knee flap (38-42), big loop preparation (BLP) for making seven big loops per trouser (47-51), small loop preparation (SLP) for stitching small loops and cutting into seven pieces required per trouser (52), adjustable rope preparation (ARP) for cutting and attaching two sets of adjustable rope at two positions on trouser waist band (65-66), and main body assembly (MBA) for assembling all the prepared parts and other parts (do not require preparation) to the trouser body and involves other operations such as trimming, turning, quality checking, and

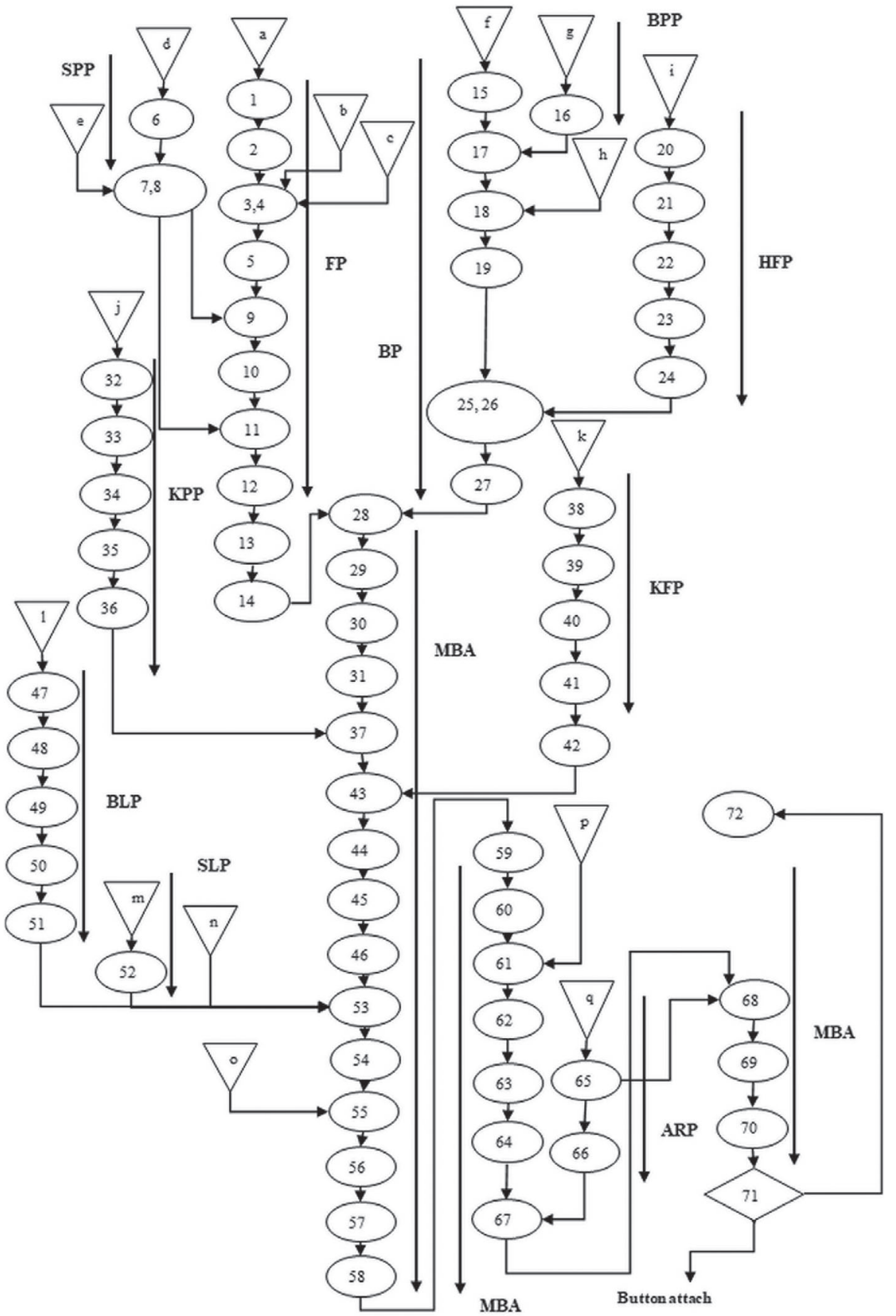

FIGURE 3 Conceptual model of Trouser assembly line. a, Left flybox; b, leg front; c, knee patch; d, right flybox; f, leg back; g, back patch; h, hip pocket; i, hip flap; j, knee pocket; k, knee flap; l, big loop; m, small loop; n, waist band; o, company tags and size label; p, bottom leg rope; q, adjustable rope

rework (28-31, 37, 43-46, 53-64, 67-72). The splitting of the trouser assembly line into sections was done for the purpose of effective capturing of all the operations involved in the line.

3.2 Modeling of inputs

The trouser assembly line system consisted of 72 tasks. However, each task is completed and repeated at different times. Therefore, to understand and measure the processing task times for each workstation in the line, continuous stopwatch time study combined with observation was conducted.[70] The observed times in seconds were first converted to standard time units (minutes) and then recorded. The total of 60 observed times for each task were obtained comprising of 20 measurements recorded at intervals of three periods of production season. The processing times measurement was done

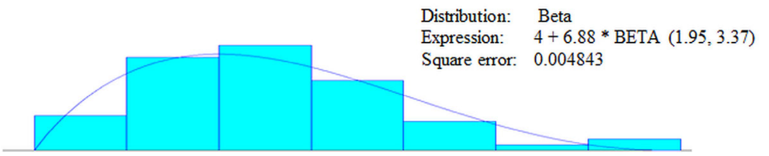

FIGURE 4 Left front rise overlock fitted processing time distribution

on single cut piece and single workpiece rather than bundles. However, each operator and helper in the preparatory sections seizes and releases bundle to the next workstation after completing the task on each cut piece in the bundle. While single workpiece is seized and released in MBA. Therefore, the processing times for completing task on the bundle was calculated using Equation (1).

$$\text{Bundle processing time} = \text{Cut picece processing time x Bundle size}, \tag{1}$$

where, bundle processing time is the time taken for completing task on the bundle, cut piece processing time is the observed time for each task performed on the cut piece. This was only applied to preparatory sections. Thus, the processing times modeling was done for both bundle and single workpiece processing times. These sets of processing times were then analyzed using Arena input analyzer to obtained fitted candidate's probability distribution, and was accomplished for each operation involved in trouser assembly line. For instance, left front rise overlock operation has its fitted processing time probability distribution as depicted in Figure 4. Similarly, all the other operations' processing times were analyzed and summarized as shown in Table 1. Notably, all resources performing the same task in their workstation was assumed to have the same processing times as well as the fitted probability distribution.

3.3 | Construction of computer model

The computer model of the trouser assembly line was developed based on the discrete event simulation using Arena simulation software (Academic license version 16). The simulation model was built on a 64 bits notebook computer with a 2.00 GHz Intel core i3 CPU and 4.00 GB RAM. Due to the low processing speed of the notebook computer, 32 bits Arena software category was well-suited to be installed instead of the 64 bits. Consequently, the simulation model was developed and run smoothly without freezing the computer. For the computer model construction, the following model input were essential: the processing times, number of machines, number of operators, number of tasks, number of helpers, quantity of input material per day, interarrival time of parts, productivity per day, working hours, quantity of input materials per day, task precedence relations, bundle sizes, job release policy, machine type, and production target. While the output variables from the Arena model included cycle time, idle time, resource utilization, throughput, defect, and work in progress (WIP). However, only throughput was used for Arena model validation and OptQuest optimization. WIP was adopted to determine the global best line balancing condition.

In the construction of computer model or base model, several Arena simulation elements were used including entity, variables, resources, process, attribute, and transfer and control logic elements. The following model assumptions were used for simulation model development in this study:

1. The input materials arrived in production line at constant time, that is, every day and there was no shortage of materials from cutting department.
2. There was no breakdown of the machines in the production line
3. There were no absenteeism of the operators and helpers, and so the workstations are never stopped due to absence of the operators or helpers.
4. Helpers were not allowed to operate any machine, only operators are assigned to machines. Therefore, the number of operators were equal to the number of machines and increasing machine number also increases operator number and vice versa.
5. The daily production shift was 8 hours, and there was no overtime considered.
6. All defected trousers at 8% defect rate per day were reworked by only one workstation with a single needle lockstitch machine.
7. Infinite buffer (workstation's bundles or workpieces storage) capacity was considered which implies that the buffer at each workstation could never be full.

TABLE 1 Fitted processing times probability distributions for operations

WSN	OPN	Operations description	Resource	Processing time distribution per resource
1	1	Left flybox pressing	Iron press	TRIA (3, 5.12, 5.9)
2	2	Buttonhole on Left flybox	Buttonhole machine	6.05 + ERLA (0.39, 6)
3	3	Left front rise overlock	Overlock machine	4 + 6.88 * BETA (1.95, 3.37)
	4	Right front rise overlocks		2.29 + ERLA (0.239, 5)
4	5	Knee patch attach	Single needle lockstitch	20 + 21 * BETA (0.856, 1.33)
5	6	Side pocket flatlock	Flatlock machine	4 + 4 * BETA (1.94, 2.74)
6	7	Side pocket overlocks	Overlock machine	2 + ERLA (0.555, 2)
	8	Right flybox overlock		1.6 + LOGN (0.719, 0.418)
7	9	Side pocket attach	Single needle lockstitch	7 + 11 * BETA (1.67, 1.67)
8	10	Side pocket topstitch	Single needle lockstitch	10 + GAMM (1.44, 2.7)
9	11	Right flybox attach	Single needle lockstitch	TRIA (13, 20.7, 25)
10	12	Left fly box tacking	Single needle lockstitch	9 + WEIB (3.39, 2.09)
11	13	Fly attach	Single needle lockstitch	12.1 + GAMM (0.955, 3.94)
12	14	Front prep bundling	Helper	5 + 10 * BETA (1.27, 2.07)
13	15	Back marking	Helper	3 + 4.65 * BETA (1.55, 2.76)
14	16	Back patch pressing	Iron press	TRIA (3, 8.29, 9.73)
15	17	Back patch attach	Single needle lockstitch	10 + 11 * BETA (0.737, 0.96)
16	18	Hip pocket cutting	Automatic wallet machine	TRIA (3.17, 3.99, 7)
17	19	Hip pocket overlocks	Overlock machine	5 + 3.83 * BETA (2.14, 3.14)
18	20	Hip flap folding	Helper	NORM (4.77, 0.65)
19	21	Button Hole on hip flap	Button hole machine	3.55 + GAMM (0.194, 5.47)
20	22	Hip flap runstitch	Single needle lockstitch	3 + LOGN (2.72, 1.83)
21	23	Hip flap turning	Turning machine	NORM (3.25, 0.551)
22	24	Hip flap topstitches	Single needle lockstitch	3 + 5 * BETA (1.7, 1.88)
23	25	Hip flap attach	Single needle lockstitch	5.45 + LOGN (1.44, 0.936) 19 + 10 * BETA (1.46, 1.46)
	26	Hip pocket finish		
24	27	Back prep bundling	Helper	3 + 2 * BETA (0.889, 0.968)
25	28	Front and back bundling	Helper	2 + 6.86 * BETA (1.18, 2.11)
26	29	Side seam overlock	Overlock machine	NORM (1.21, 0.115)
27	30	Side seam topstitch	Feed of arm	TRIA (0.52, 0.747, 0.94)
28	31	Knee pocket point marking	Helper	0.32 + 0.57 * BETA (0.889, 1.18)
29	32	Knee pocket topstitch	Single needle lockstitch	11 + ERLA (1.89, 2)
30	33	Knee pocket tacking	Single needle lockstitch	4 + 3 * BETA (1.33, 1.75)
31	34	Knee pocket Overlock	Overlock machine	2 + 4 * BETA (0.831, 2.05)
32	35	Knee pocket hemming	Single needle lockstitch	2 + 4 * BETA (1.41, 1.13)
33	36	Knee pocket ironing	Iron press	8 + 5.78 * BETA (0.957, 1.06)
34	37	Knee pocket attach	Single needle lockstitch	0.88 + 0.92 * BETA (1.77, 1.96)
35	38	Knee flap folding	Helper	3.63 + 3.13 * BETA (3.89, 2.38)

(Continues)

TABLE 1 (Continued)

WSN	OPN	Operations description	Resource	Processing time distribution per resource
36	39	Button hole on knee flap	Button hole machine	4.27 + WEIB (1.21, 1.99)
37	40	Knee flap runstitch	Single needle lockstitch	TRIA (2.37, 3.81, 6.88)
38	41	Knee flap turning	Turning machine	NORM (4.02, 1.01)
39	42	Knee flap topstitch	Single needle lockstitch	4 + 5.78 * BETA (0.903, 2.11)
40	43	Knee flap attach	Double needle lockstitch	TRIA (0.67, 1.04, 1.7)
41	44	Bar tacking	Bartack machine	NORM (1.25, 0.266)
42	45	Back rise overlocks	Overlock machine	0.26 + LOGN (0.185, 0.0881)
43	46	Back rise topstitches	Double needle lockstitch	NORM (0.439, 0.0494)
44	47	Big loop matching	Helper	NORM (0.0663, 0.018)
45	48	Big loop runstitch	Single needle lockstitch	0.12 + 0.3 * BETA (2.89, 5.28)
46	49	Big loop turning	Turning machine	0.07 + GAMM (0.0143, 7.47)
47	50	Big loop runstitch	Single needle lockstitch	0.09 + 0.19 * BETA (1.78, 2)
48	51	Big loop button hole	Button hole machine	TRIA (0.04, 0.055, 0.11)
49	52	Small loop runstitch	Loop stitch machine	TRIA (0.11, 0.134, 0.18)
50	53	Small loop, big loop, and waistband attach	Single needle lockstitch	1.58 + ERLA (0.068, 7)
51	54	Waistband topstitch	Single needle lockstitch	TRIA (0.73, 1.34, 1.5)
52	55	Waist band closing with company tags and size label	Single needle lockstitch	0.77 + GAMM (0.0607, 3.58)
53	56	Inseam overlock	Overlock machine	0.49 + WEIB (0.483, 6.16)
54	57	Trouser turning	Helper	0.2 + LOGN (0.218, 0.112)
55	58	Inseam topstitch	Feed of arm	0.32 + 0.56 * BETA (1.98, 1.61)
56	59	Button hole on Hip band	Button hole machine	TRIA (0.31, 0.344, 0.47)
57	60	Button hole on the bottom leg	Button hole machine	0.32 + 0.2 * BETA (2.7, 3.33)
58	61	Bottom rope attach	Helper	0.5 + LOGN (0.251, 0.168)
59	62	Bottom hemming	Single needle lockstitch	0.71 + 0.73 * BETA (2.04, 2.6)
60	63	Small loop tacking	Single needle lockstitch	TRIA (0.82, 1.17, 1.37)
61	64	Final bartacking	Bartack machine	TRIA (0.74, 0.851, 1.05)
62	65	Adjustable rope cutting	Helper	TRIA (0.1, 0.145, 0.19)
63	66	First adjustable rope hemming	Single needle lockstitch	TRIA (0.1, 0.136, 0.2)
64	67	First adjustable rope attach	Single needle lockstitch	NORM (0.75, 0.0479)
65	68	Second adjustable rope attach	Single needle lockstitch	0.53 + 0.32 * BETA (3.19, 2.1)
66	69	Button point marking	Helper	0.55 + GAMM (0.0328, 6.16)
67	70	Trimming	Helper	NORM (4.84, 0.345)
68	71	Quality checking	Quality personnel	0.82 + LOGN (0.332, 0.154)
69	72	Rework	Single needle lockstitch	TRIA (2, 3.5, 4.7)

Abbreviations: OPN, operation number; WSN, workstation number.

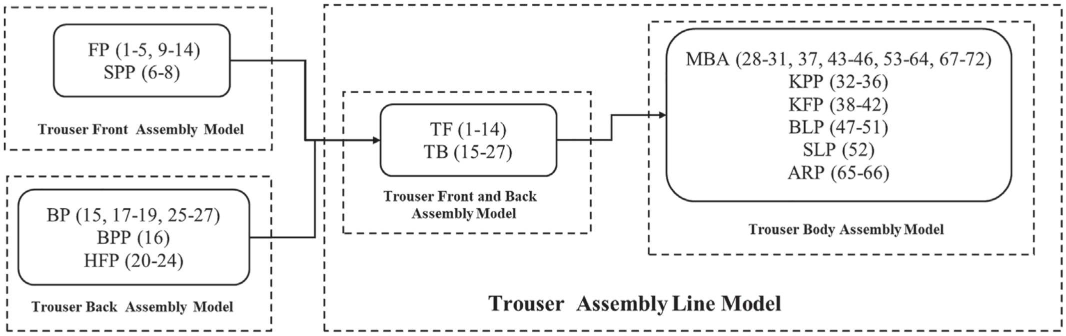

FIGURE 5 Computer simulation model construction approach for this study

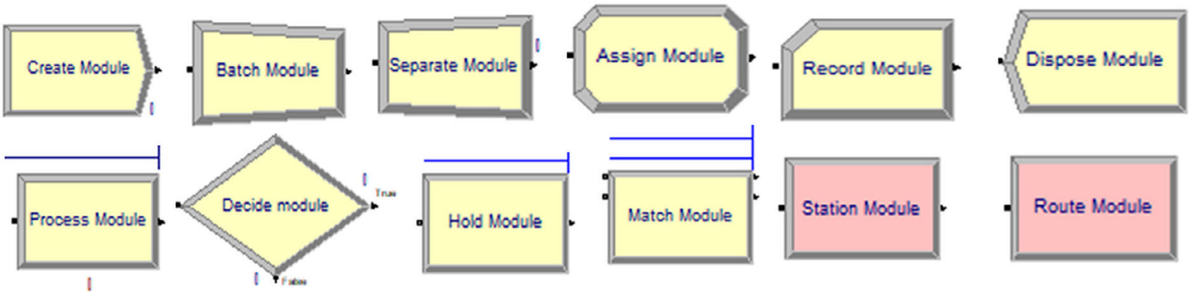

FIGURE 6 Arena modules used for discrete event simulation model development

In order to build a model of a complex trouser assembly line, four separate simulation models were developed and then combined as shown in Figure 5. TF assembly model is made of FP and SPP sections. TB assembly model consists of BP, BPP, and HFP sections. The combination of TF and TB models formed TF and back assembly model. Trouser body assembly model is made of MBA, KPP, KFP, BLP, SLP, and ARP sections.

The construction of simulation models with Arena, involved using modeling shapes, called modules, from the basic process, advanced process, and advanced transfer panels. These modules are used as the building blocks in developing a simulation model. There are two types of modules which include data module and flowchart module. In the data modules (eg, resource, queue, variable, schedule, and set), the user can manipulate these modules in the spreadsheet interface, which are not placed in the model window. While for the flowchart modules, the user places flowchart modules in the model window and connects them to form a flowchart, which describes the logic of model. The flowchart modules from three Arena project bars were utilized: basic process (create module, batch module, separate module, assign module, record module, process module, and decide module), advanced process (hold module and match module), and advance transfer (station module and route module). These Arena flowchart modules are depicted in Figure 6.

The Arena flowchart modules used in this study were as follows;

1. *Create module* was used to mimic the trouser parts bundles' arrival from the cutting department to the assembly line. The number of Arena create modules used were the same as the number of parts on the trousers except for bundles that do not require preparation process including company tags and size label, waist band, knee patch, and bottom leg rope.
2. *Batch module* was used to combine individual cut pieces into bundles to be moved to the next operators in the MBA section.
3. *Separate module* was used to separate the bundles of workpieces to be seized and released as a single workpiece by the operators in MBA.
4. *Assign module* was used to add attributes, names, pictures, and variables to the entities (trouser parts bundles or workpieces).
5. *Record module* was employed to count the throughput at end of FP, BP, and the full assembly line.

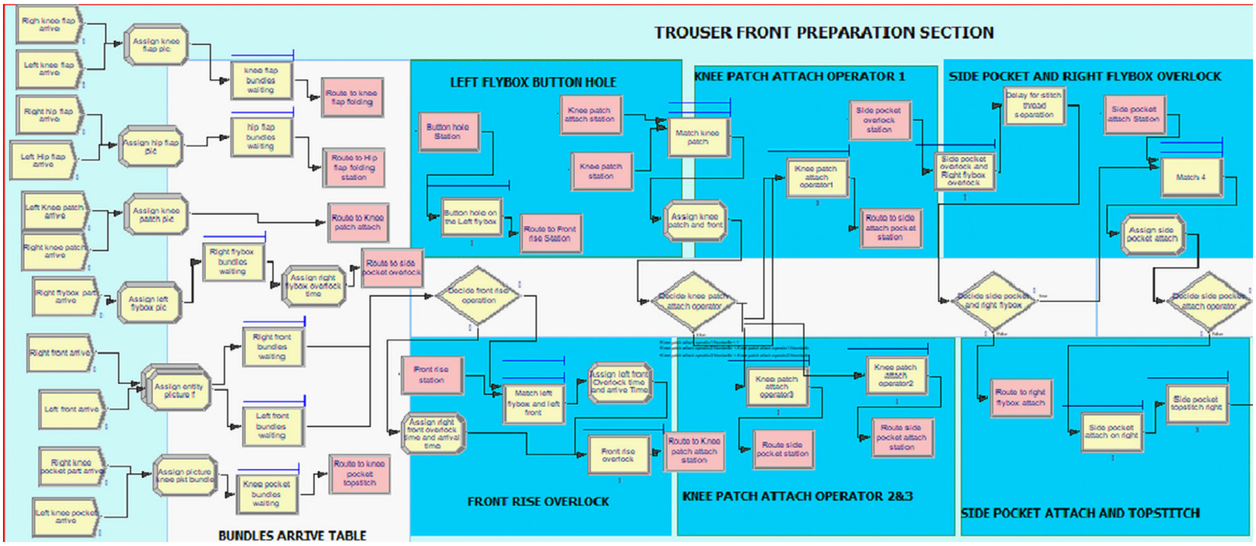

FIGURE 7 Arena simulation model for front preparation section

6. *Process module* was used to model the working of resources (machines, helpers, quality personnel) in completing the given tasks. In fact, each process module was used to represent the one resource at each workstation. This implies that total process modules used were equivalent to the total number of the available resources in the trouser assembly line. Operator and machine were modeled as single resource, but denoted as machine of different types (eg, overlock, single needle lockstitch, flatlock, and so on).
7. *Decide module* was used to make decision on bundles or workpieces distribution to the resources in the same workstation. It was also used to model the task assignment pattern to operators whether equal workload or unequal workload on the operators performing similar tasks, moreover, it was used to decide on quality whether rework required or not.
8. *Hold module* was used to model job release policy based on the WIP threshold of the bottleneck workstation. It holds the bundles generated by the create module and only releases some bundles restricted by the set WIP threshold of the bottleneck workstation. The bottleneck workstation is the one whose capacity is less than the demand placed on it and less than the capacities of all other resources. WIP is the number of unfinished bundles or workpieces in the workstations.
9. *Match module* was employed to combine two or different parts bundles to a workstation and it was used in almost all the trouser assembly line sections. In addition, four Arena models developed were combined using match module to form a full trouser assembly line model. In using match module, all trouser parts bundles and workpieces were captured, and in case of missing parts, there could be no trouser output at end of the assembly line.
10. *Station and Route modules* are complementary modules of advance transfer. They were used to replace the modules connecting links which eliminated the congestion of the simulation model.
11. *Dispose module* was used as the exit for finished trousers at end of the assembly line.

All these Arena modules played great roles in building simulation model of the complex trouser assembly line. Basically, developing a simulation model involved identifying one or more flow objects known as entities that flow through the system and then building a flowchart of the model using Arena's flowchart modules. In the simulation of trouser assembly line, the bundles arrive in the line with the interarrival time of 8 hours, the bundles were held at the bundle arrive table using hold modules, which were then transferred to the specific workstations using the route and station modules as shown in Figure 7. The full simulation model of trouser assembly line (base model) is deposited at https://doi.org/10.17632/T5W96KH5W7.1.[71]

3.4 | Verification and validation

After developing the computer model, the simulation runs were conducted to verify if the model follows the logic pointed out in the conceptual model. Verification is basically the process of ensuring that the model behaves as intended.[72] More specifically, it is known as debugging the model. Therefore, traces and animation techniques were used to verify that each program path is correct (Figure 8). Furthermore, model verification was done through testing and observing the simulation model at varying situations including changes made on the interarrival time, processing times, run length, and replication number.

The simulation replication length (n = 10) was determined in accordance to Kelton et al[72] with the run length of one month (ie, 28 days of 8 hours daily production). In this study, the steady-state simulation with 2 days warm-up period was approximated according to Law.[73] Then, the Arena simulation runs were executed, and the specified Arena output variable, that is, average throughput ($\mu_A = 496$ pieces per day) with the half width (6.61) was obtained. The hypothesized mean (μ_A) was used for comparison with real-world system throughput samples. The real-world system throughput with sample size (N = 23) collected for a period of one month from real-world system was used for validation of the operation model. One-sample T-test at 95% confidence interval (CI) was successfully accomplished with the help of Minitab statistical software (version 18). Since μ_A lies within 95% CI for real-world system average throughput (μ_R), the null hypothesis (H_0) was accepted with the T-value (−0.2) and *P*-value (.842) as shown in Table 2. Hence, the Arena simulation model of trouser assembly line was validated including all the assumptions used in building the model.

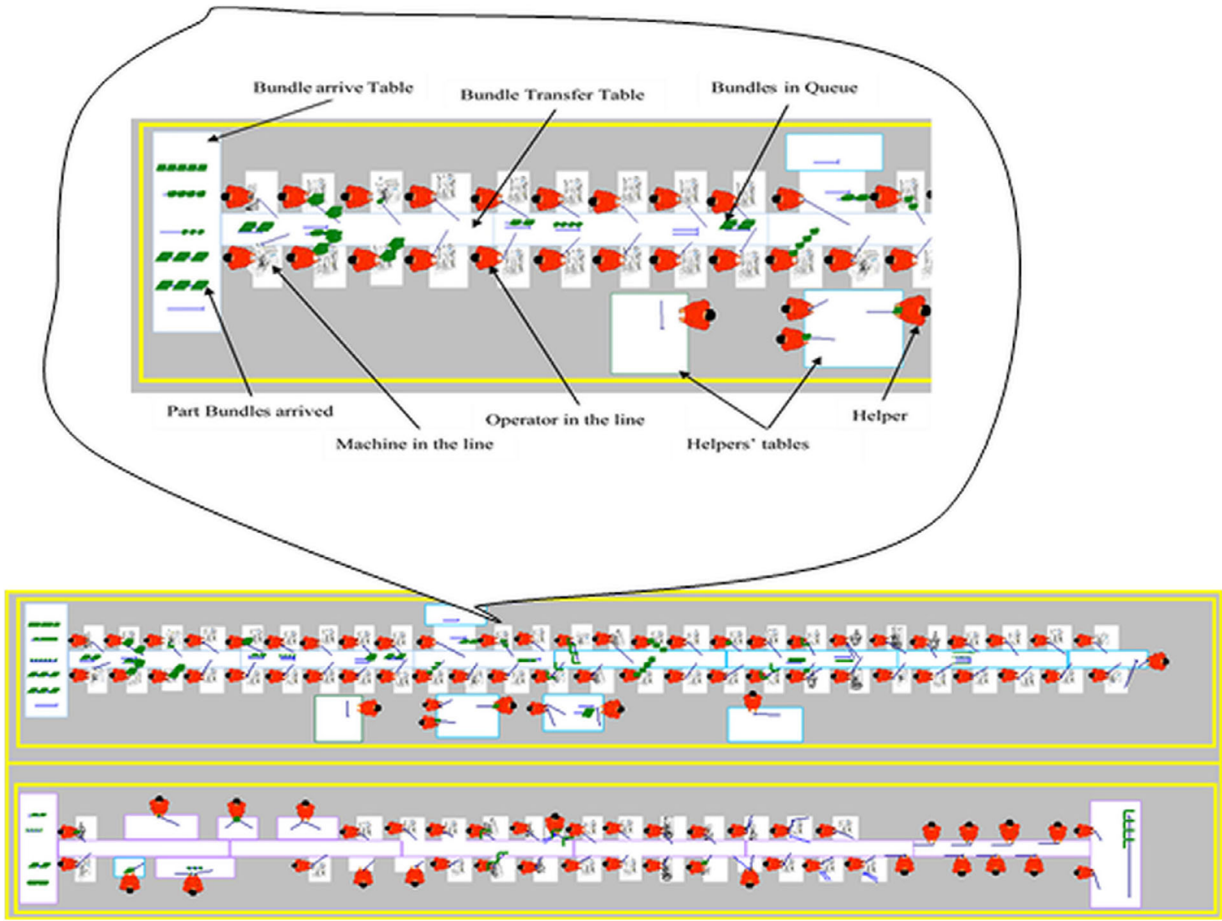

FIGURE 8 Arena animation of trouser assembly line operations

TABLE 2 Descriptive statistic for real-world throughput sample and hypothesis test

N	Mean (μ_R)	StDev	SE Mean	95% CI for μ_R	*T*-value	*P*-value	Null hypothesis	Alternative hypothesis
23	490.8	124.2	25.9	(437.1, 544.5)	−0.20	.842	$\mu_R = \mu_A$, H_0	$\mu_R \neq \mu_A$, H_1

Note: N, number of throughput samples from real-world system.

3.5 | Scenarios generation and optimization model

In order to narrow down the search space of the optimization process, 16 trouser assembly line design scenarios were generated through simulation experiments. The resolution-V experimental design with five factors each at two levels: bundle size (10, 40), job release policy (policy, no policy), task assignment pattern (equal, random), machine number (increase 4, reduce 4), and helper number (increase 3, reduce 3) was used. Resolution-V design method was selected because it is suitable for design of simulation experiments with reduced number of design points.[74] The purpose of scenarios generation in this article was to determine the best design scenario that provides a local optimal solution to be adopted as the initial decision variables for the optimization process.

A black box optimization on the trouser assembly line simulation model was performed using OptQuest for Arena. OptQuest treats the simulation model as a black box because it observes only the input/output of the simulation model. OptQuest combines the metaheuristics of tabu search, neural networks, and scatter search into a single search heuristic. The fundamental principal behind OptQuest optimization process is that if a candidate solution does not fit the constraints, then that solution is eliminated and OptQuest explores candidates that are more likely to be better (Figure 9). OptQuest accord the simulation analysts to explicitly determine integer and linear constraints on the deterministic simulation inputs.[68]

The implicit mathematical formulation of the optimization problem is illustrated by Equation (2).

$$\begin{aligned} &Max(\text{TH}) = f_i(A_C, A_S, A_L) \text{ at constant } (A_S, A_L) \\ &\text{Subjected to } (s.t): \\ &(A_C, A_S, A_L) \leq A_i \\ &\text{LB} \leq A_c \leq \text{UB} \end{aligned} \tag{2}$$

where TH represents the average production throughput of trouser assembly line which is expressed as a function of model input variables ($f_i(A_C, A_S, A_L)$), $h_i(A_C, A_S, A_L)$ represents function of constraints on the model control factors (A_C), model stochastic factors (A_S), and model logic control (A_L), A_i is set of model constraints which include precedence constraints, limits on the production resources and constraints on model control factors. LB and UB are the lower and upper bound on A_C. A_C are known as decision variables including bundle size, job release policy, machine number, and helper number. A_S are fixed variables that are used for building the computer model (eg, processing time, availability of resources, defect rate, rework, machine reliability, interarrival, and interdeparture time). A_L are fixed qualitative variables that are more logical or structural in nature coded in the Arena simulation software (eg, process routing, queue discipline, dispatching rule).

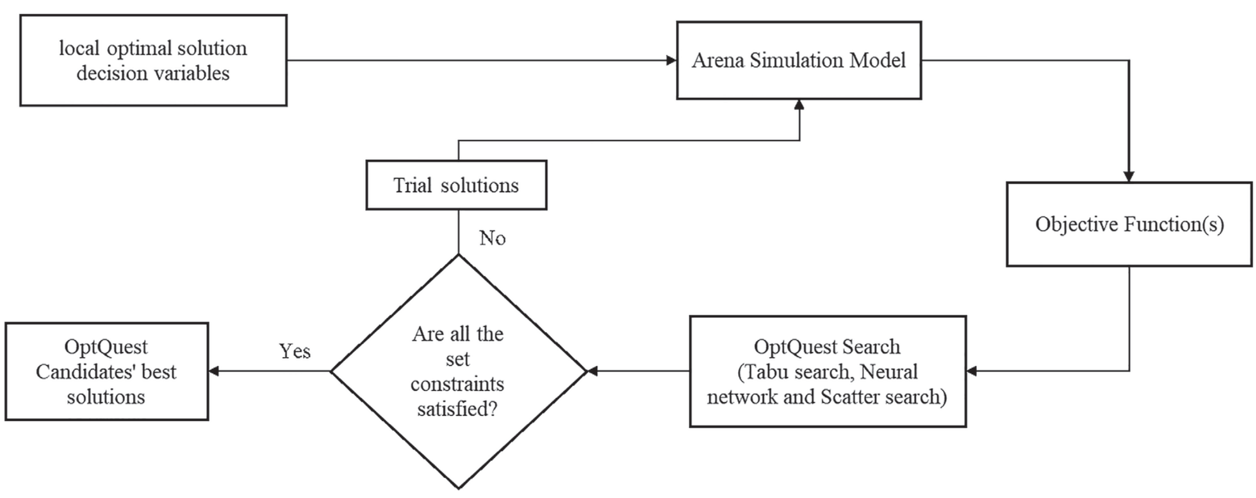

FIGURE 9 OptQuest optimization process

4 | RESULTS AND DISCUSSION

4.1 | Design scenarios

To this end, simulation experiments were performed on 16 assembly line balancing scenarios[71] while observing the response (throughput) for each design scenario. As shown in Figure 10, scenario 2 stand out with the highest average throughput. Increasing both number of machines and helpers in their respective bottleneck workstations increases the average throughput of the trouser assembly line. This is because increasing resources in the workstation reduces the cycle time, hence, increase in the average throughput.[75] Scenario 2 was selected to be the local optimal solution for trouser assembly line balancing which was used as the initial best solution for OptQuest optimization process. The parameter settings for the selected design scenario included bundle size (25), job release policy (no policy), task assignment pattern (equal), machine number (increase 3 single needle lockstitch and 1 iron press), helper number (increase 3).

4.2 | OptQuest optimization

The objective function for the optimization model was to maximize the throughput, and only two control factors (machine number and helper number) were considered. This is because the other three factors were determined to be statistically insignificant by analysis of variance at alpha value of .05. Due to operational cost consideration, NYTIL garment facility management has set the number of resources available for addition: 10 machines and five helpers. The number of resources to be added at specific workstations must not exceed 3. The present study proposed an optimization model to find the possible combination of a number of resources that maximizes average production throughput subjected to limited number of resources. The mathematical formulation for this problem is expressed as in Equation (3) which was derived from Equation (2) putting in mind that all other model control factors have been considered constant except the resources, that is, machine number and helper number.

$$
\begin{aligned}
& Max(\mathrm{TH}) = f(X_i, Y_i) \\
& s.t: \\
& h(X_i) \leq 10 \\
& h(Y_i) \leq 5 \\
& 1 \leq X_i \leq 3 \\
& 1 \leq Y_i \leq 3 \\
& X_i \text{ and } Y_i \text{ are the integers } i = 1, 2, 3, \ldots, n
\end{aligned} \tag{3}
$$

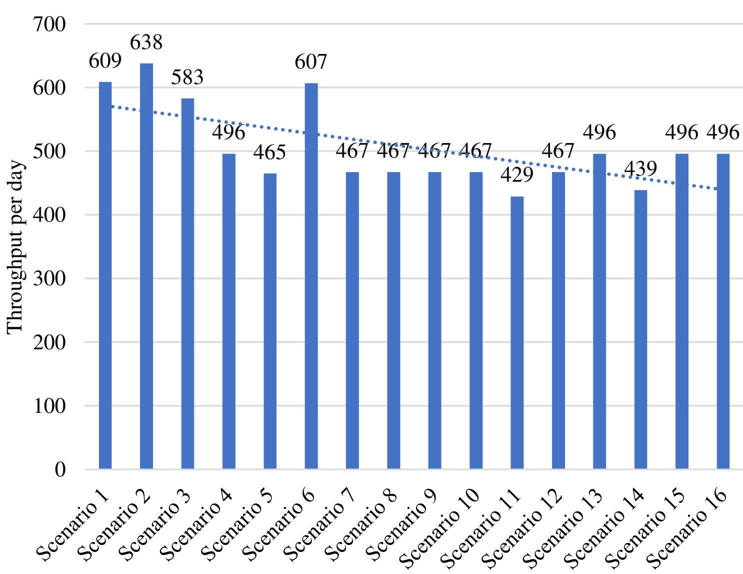

FIGURE 10 Assembly line balancing scenarios

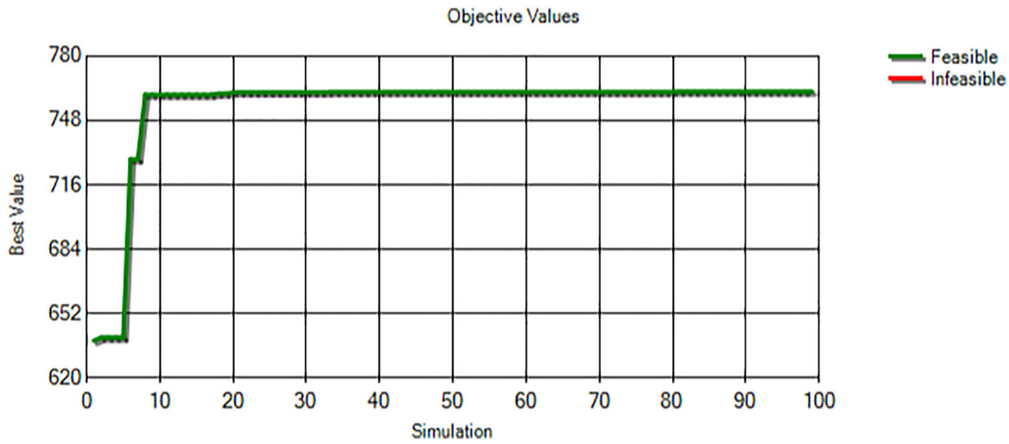

FIGURE 11 OptQuest optimization results

where TH is expressed as the objective function of the discrete input variables (machine number (X_i) and helper number (Y_i)), h represents the constraints on machines and helpers, n represents the total number of constraints resources. The values for the resource constraints were determined based on the discussion with NYTIL garment department management. Because of the discrete input variables, single objective function, stochastic nature of processing times used in building the simulation model, and objective function has factor (machine number and helper number) interaction, this kind of optimization problem is known as nonlinear stochastic and single objective optimization with discrete control values.[15,50]

An optimization process was executed with automatic termination of approximately 100 simulations. Each simulation presented feasible optimal solutions as shown in Figure 11. The feasible optimal solutions are set of discrete control variables that satisfy both constraints on number of machines and helpers to the desired degree of precision.

4.3 | Optimal solution

At the end of the optimization process, OptQuest presented 20 best line balancing solutions for each simulation out of 100 total simulations performed as presented in Table 3. The differences in the objective value (throughput) among these best solutions are negligible because they differ infinitesimally. Therefore, it was a great challenge to select the global optimal solution from the 20 candidate's best solutions. Nevertheless, three outstanding best solutions were selected by consideration of resource numbers. In this respect, they utilized fewer resources than other simulations. However, from the three selected candidate's solutions (Simulation 33, 32, and 8), further decision was taken to obtain global best solution. In order to unlock this, a separate Arena simulation model was created for each case and the simulation experiments were performed to observe the WIP at workstations. Simulation 33 presented lower WIP at the workstations but utilizes more resources than simulation 32 and simulation 8. Therefore, it was eliminated. Although simulation 8 has less resource than simulation 32, it accumulated high WIP at bartacking workstation. For this reason, simulation 32 was determined to be the global optimal line balancing solution because it has low WIP in all workstations. WIP of workstations can easily be observed from the simulation model without need for calculation.[76] Therefore, it was employed in this study to foster the decision making on determination of global optimal garment assembly line balancing.

It was observed that increasing the resources leads to increase of throughput. However, it is only true when resources are added at bottleneck workstations. There were 15 bottleneck workstations identified in the trouser assembly line as highlighted in Table 4. The bottleneck workstation is the one whose capacity is less than the demand placed on it and less than the capacities of all other resources. It was effectively determined through extensive simulation of the assembly line while observing the WIP at each workstation. Therefore, NYTIL garment facility is recommended to implement the global optimal line balancing solution in order to achieve an increase in the throughput, and attain the sustainability of their assembly systems.

TABLE 3 Optimal line balancing candidates' solutions

		Number of resources (machine and helper) added			
Simulation	Objective value	Overlock machine	Bartack machine	Helper	Single needle lockstitch
80	762.3	1	2	2	4
40	762.2	1	1	2	5
43	762.2	1	1	2	5
33	762.1	1	1	2	4
81	762.1	2	2	2	3
45	762.0	1	1	2	4
20	761.9	1	0	2	5
32	761.8	1	1	2	3
74	761.6	1	2	2	4
77	761.6	1	2	2	3
18	761.4	2	1	2	4
29	761.3	1	1	2	5
79	761.3	1	0	2	6
28	761.2	2	0	2	4
42	761.1	2	0	2	5
34	761.0	1	0	2	5
41	761.0	0	1	2	6
8	760.9	1	0	2	3
30	760.9	1	0	2	5
71	760.7	1	2	2	5

4.4 | Line balancing performance indicators

In this study, the ALBP solution approach was arrived at indirectly through maximization of throughput. This is because throughput increase is strongly correlated to reduction of cycle time and low WIP.[75] Therefore, the cycle time of the line balancing condition was estimated based on the throughput using Equation (4).[42]

$$\text{Cycle time} = \frac{\text{Production Time per day}}{\text{Throughput per day}}, \tag{4}$$

where, cycle time is an amount of time for which a workpiece remains in a workstation. Production time per day is 8 hours or 480 minutes. This ALBP approach is suitable for garment assembly line systems in which bundles and single workpieces are moved from one workstation to another simultaneously. The cycle time was calculated for each line balancing condition: existing, local optimal, and global optimal as shown in Table 5. The result showed that the throughput increased by 30% for local optimal, and 55% for global optimal with reduction of cycle time by 23% and 36%, respectively. The cycle time is adopted as key performance indicator at this point because its minimization is the objective problem for the present ALBP solution approach.

Anisah et al[75] achieved an increase in the average throughput by 28.47% with 65.45% reduction of cycle time at local optimal solution, when resources were added to workstations of a T-shirt assembly line. The authors considered stochastic task times but no bundles processing and optimization. Their findings are not far cry from the present results for the local optimal line balancing condition. Yemane et al[6] achieved line efficiency increase from 72.5% to 75.3% at the optimal solution for T-shirt assembly line balancing using Arena/Optquest tool and deterministic task times with no bundles

TABLE 4 Resource capacity allocation per workstation for existing, local optimal and global optimal line balancing conditions

WSN	OPN	Operation description	Resource	*Existing*	*Local optimal*	*Global optimal*
1-**B**	1	Left flybox pressing	Iron press	1shared	1	1
2	2	Buttonhole on Left flybox	Buttonhole machine	1	1	1
3	3	Left front rise overlock	Overlock machine	1	1	1
	4	Right front rise overlocks				
4-**B**	5	Knee patch attach	Single needle lockstitch	3	4	4
5	6	Side pocket flatlock	Flatlock machine	1	1	1
6	7	Side pocket overlocks	Overlock machine	1	1	1
	8	Right flybox overlock				
7	9	Side pocket attach	Single needle lockstitch	2	2	2
8	10	Side pocket topstitch	Single needle lockstitch	2	2	2
9	11	Right flybox attach	Single needle lockstitch	2	2	2
10	12	Left fly box tacking	Single needle lockstitch	2	2	2
11	13	Fly attach	Single needle lockstitch	2	2	2
12	14	Front prep bundling	Helper	1	1	1
13	15	Back marking	Helper	1	1	1
14-**B**	16	Back patch pressing	Iron press	1shared	1	1
15	17	Back patch attach	Single needle lockstitch	2	2	2
16	18	Hip pocket cutting	Automatic wallet machine	1	1	1
17	19	Hip pocket overlocks	Overlock machine	1	1	1
18	20	Hip flap folding	Helper	1	1	1
19	21	Button Hole on hip flap	Button hole machine	1	1	1
20	22	Hip flap runstitch	Single needle lockstitch	1	1	1
21	23	Hip flap turning	Turning machine	1	1	1
22	24	Hip flap topstitches	Single needle lockstitch	1	1	1
23-**B**	25	Hip flap attaches	Single needle lockstitch	2	3	3
	26	Hip pocket finish				
24	27	Back prep bundling	Helper	1	1	1
25	28	Front and back bundling	Helper	1	1	1
26-**B**	29	Side seam overlock	Overlock machine	2	2	3
27	30	Side seam topstitch	Feed of Arm	2	2	2
28-**B**	31	Knee pocket point marking	Helper	1	1	2
29	32	Knee pocket topstitch	Single needle lockstitch	2	2	2
30	33	Knee pocket tacking	Single needle lockstitch	1	1	1
31	34	Knee pocket Overlock	5 threads overlock	1	1	1
32	35	Knee pocket hemming	Single needle lockstitch	1	1	1
33	36	Knee pocket ironing	Iron press	2	2	2
34-**B**	37	Knee pocket attach	Single needle lockstitch	2	2	3

(Continues)

TABLE 4 (Continued)

WSN	OPN	Operation description	Resource	*Existing*	*Local optimal*	*Global optimal*
35	38	Knee flap folding	Helper	1	1	1
36	39	Button hole on knee flap	Button hole machine	1	1	1
37	40	Knee flap runstitch	Single needle lockstitch	1	1	1
38	41	Knee flap turning	Turning machine	1	1	1
39	42	Knee flap topstitch	Single needle lockstitch	1	1	1
40	43	Knee flap attach	Double needle lockstitch	2	2	2
41-**B**	44	Bar tacking	Bartack machine	2	2	3
42	45	Back rise overlocks	Overlock machine	1	1	1
43	46	Back rise topstitches	Double needle lockstitch	1	1	1
44-**B**	47	Big loop matching	Helper	1	2	2
45	48	Big loop runstitch	Single needle lockstitch	3	3	3
46	49	Big loop turning	Turning machine	2	2	2
47	50	Big loop runstitch	Single needle lockstitch	2	2	2
48	51	Big loop button hole	Button hole machine	1	1	1
49	52	Small loop runstitch	Loop stitch machine	1	1	1
50-**B**	53	Small loop, big loop and waistband attach	Single needle lockstitch	3	4	4
51	54	Waistband topstitch	Single needle lockstitch	2	2	2
52	55	Waist band closing with size and label tags	Single needle lockstitch	2	2	2
53	56	Inseam Overlock	Overlock machine	2	2	2
54	57	Trouser turning	Helper	1	1	1
55	58	Inseam topstitch	Feed of arm	2	2	2
56	59	Button hole on Hip band	Button hole machine	1	1	1
57	60	Button hole on the bottom leg	Button hole machine	1	1	1
58-**B**	61	Bottom rope attach	Helper	1	2	2
59	62	Bottom hemming	Single needle lockstitch	2	2	2
60	63	Small loop tacking	Single needle lockstitch	2	2	2
61	64	Final Bar tacking	Bartack machine	2	2	2
62	65	Adjustable rope cutting	Helper	1	1	1
63	66	Adjustable hemming	Single needle lockstitch	1	1	1
64-**B**	67	First adjustable rope attach	Single needle lockstitch	1	1	2
65-**B**	68	Second adjustable rope attach	Single needle lockstitch	1	1	2
66-**B**	69	Button point marking	Helper	1	1	2
67-**B**	70	Trimming	Helper	7	8	8
68	71	Quality checking	Quality personnel	2	2	2
69	72	Rework	Single needle lockstitch	1	1	1

Abbreviations: B, bottleneck workstation; OPS, operation sequence; WSN, workstation number.

TABLE 5 Comparison of the line balancing conditions

S/N	Performance indicator	Existing	Local optimal	Global optimal
1	Total number of helpers	19	22	24
2	Total number of machines	83	87	92
3	Total number of operators	83	87	92
4	Number of quality personnel	2	2	2
5	Number of workstations	69	69	69
6	Throughput (pieces per day)	490	638	762
7	Cycle time (minutes)	0.98	0.75	0.63

processing. Their results showed very small increment as compared with the present results although line efficiency was not determined in this study. But it can be depicted from large the decrease in the cycle time obtained, as the two performance indicators are correlated. Dinh et al[48] proposed a simulated annealing approach for ALBP in Polo-Shirt assembly line. The authors used the greedy strategy to find an initial solution, then applied the simulated annealing to find the best line balancing solutions. In their ALBP approach, they aimed at minimizing the number of workstations for a given cycle time, and considered deterministic task times. Their ALBP objective problem is opposite to the present case. The study by Elnaggar[63] used multiobjective simulation optimization approach with Arena/OptQuest tool to determine the best number of workstations of a Shirt assembly line, and investigated the effect of operator skills levels on ALBP. The author, noted that operator skill levels affects the completion time of a certain amount of work which affect the line total output (throughput) as well as the distribution of work to each workstation.[63] In this regard, the optimal line balancing solutions obtained from the present study could have been affected by the operator skill levels though further investigation was not performed. Nonetheless, the present ALBP approach has captured more real-world situations than the previous approaches. This is because the approach considered both stochastic task times and bundles processing which are not all taken into consideration by the previous approaches. This ALBP solution approach could be applied to other woven garment products (shirts, jackets, shorts, uniforms, and so on) manufacturing as they also require bundle progressive garment production system. However, it could also be well-applied in knitwear garments products (T-shirt, sweater, polo-shirt, and so on) and footwear products manufacturing although they do not operate on bundle progressive system.

5 | CONCLUSION AND RECOMMENDATION

In this article, SBO was proposed to solve ALBP for complex garment manufacturing system with consideration of stochastic task times and bundles processing. The objective problem of the present ALBP is to minimize the cycle time while maintaining constant number of workstations. This was achieved indirectly through maximizing the throughput of the trouser assembly line using SBO and then the cycle time was determined from it. The conceptual model was constructed based on the existing practice on the trouser assembly line which was validated by line supervisors. Most details on the trouser production process was captured during conceptual modeling which simplified the development of the simulation model and contributed to its validation as an acceptable approximate of real-world trouser assembly line at 95% CI. Increasing the number of resources in the bottleneck workstations increased the average production throughput and reduced cycle time at both local and global optimal line balancing conditions. The increase in throughput and decrease in cycle time confirmed the suitability of garment assembly line balancing using SBO. This is because the local optimal solution narrowed down the search space of the OptQuest optimization process and thus, OptQuest rapidly and aggressively reached the global optimal solutions. The ALBP solution approach is practicable to managers for decision making on garment assembly line at both levels of production planning: operational, tactical, and strategic production planning. Moreover, efficient and effective line balancing condition can make garment production more sustainable while maintaining competitiveness. The proposed approach could also be applied in not only garment manufacturing sector but also applied to footwear sector. However, its main limitation is single objective optimization problem (throughput) which poses difficulty in determining the well-balanced trouser assembly line from the OptQuest candidates' best solutions.

Therefore, a further study should develop a profound optimization model (multiobjectives) with at least two objective functions including production cost and resource utilization. Furthermore, the effect of these factors: bundle size, job release policy, task assignment pattern, machine number, and helper number on the production throughput of trouser assembly line should be investigated.

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AUTHOR CONTRIBUTIONS

Ocident Bongomin: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing-original draft; writing-review and editing. **Josphat Igadwa:** Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing-original draft; writing-review and editing. **Eric Nganyi:** Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing-original draft; writing-review and editing. **Ildephonse Nibikora:** Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing-original draft; writing-review and editing.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

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