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Optimal Worker Allocation of Wooden Furniture Manufacturing System using Simulation Modeling and Data Envelopment Analysis

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***Abstract*—This study introduces the application of simulation in modeling the wooden furniture manufacturing system at the XYZ factory particularly addressing the issue of worker allocation on the production line. The XYZ factory has many workers in its furniture manufacturing system, which needs to be allocated to nine processes. The imbalance number of workers in each process will affect productivity. Simulation method is used to model the actual system. The simulation model of the actual system is verified and validated, and 45 alternatives of worker allocations are identified using Min-max operator allocation formulation. Data Envelopment Analysis - Banker, Charnes and Cooper (DEA-BCC) model is used to determine the efficiency score of each alternative. Then, DEA-cross efficiency is used to rank the alternatives. The selection criteria of the optimal worker allocation alternative are based on the total production, the average worker utilization, the average total production time, the average number of entities in the system, and the total number of workers involved in the manufacturing system. In this study, Alternative-31 (A31) is the optimal worker allocation alternative among the alternatives that have been ranked. This alternative reduces the total number of workers from 109 to 103 and decreases the average waiting time across four processes from 191.1680 to 189.7700 minutes. The application of simulation modeling, DEA-BCC and DEA-cross efficiency can help the management of the factory to make better decisions and can provide ideas to other manufacturing companies in determining the optimal worker allocation.**

Keywords*—Worker allocation, Simulation modeling, Data envelopment analysis.

I. INTRODUCTION

Since the downturn in the mid-1980s, the Malaysian furniture industry has come a long way. The industry has transformed from a bungalow-type industry to a multi-billion-ringgit export-oriented industry, which surpasses all other sub-sectors in Malaysia's large timber industry. Through a series of industrial master plans (IMP), the government has played a key role in stimulating industrial transformation by providing a stable industrial policy framework and focusing on products with added value [1].

Therefore, under this circumstance, the Malaysian furniture industry has become an important socio-economic sector. It is not surprising that while providing nearly 80,000 jobs, it created more than US$2 billion in foreign exchange income in 2015 [1]. The growth of the furniture industry is driven by increased capital investment rather than actual productivity increases. Therefore, despite the promotion of a higher degree of automation and the application of high-tech machinery, the increase in demand for factor inputs (especially raw materials and labour) is obvious [2].

Innovation from buyers and suppliers usually aims to reduce costs, and its focus is more on finding alternative raw materials, rather than adopting new processes or implementing new designs. Therefore, to

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make the transition to higher value-added fashion furniture, research shows that several issues related to factor input, policy direction, technology input and human capital development must be resolved. This requires a paradigm shift between various stakeholders to ensure the sustainable and fair growth of the furniture industry in the future. Malaysia is among the top ten furniture exporters in the world and exports about 80% of its products. Malaysia has a huge market in the United States, Japan and Australia and therefore has a strong position in the global furniture industry [3]. Malaysia has experienced tremendous export growth to the UK, UAE, Saudi Arabia, Philippines, and Russia, and is now targeting markets such as Algeria, Greece, Puerto Rico, and Libya [3].

Due to its natural resources, Malaysia has always been famous for its wooden furniture. According to the National Timber Industry Policy, the furniture industry aims to contribute RM12 billion in exports by 2020. The government will continue to support the development of the Malaysian furniture industry through various measures to ensure its rapid and sustainable growth [3]. In recent years, growth has shifted from producing ordinary products to designing its own products, which is the key to pushing Malaysia into the international arena. Foreign buyers are very popular among mid-to-high-level overseas buyers, who look to Malaysia for manufacturers that can meet their high-volume demand. Despite many economic recessions, the industry is still supported by strong global demand. Low-priced Chinese and Vietnamese furniture constitute fierce competition, while Malaysian furniture continues to be known for its original design, which emphasizes aesthetics and good professional ethics. The government also plays an important role in fostering the industry. The pro-business environment provides a pioneering position in tax exemption and investment tax relief, making business easier and faster [3]. Malaysia has a good business environment, high-quality products, and a high potential market. It is expected to exceed expectations and continue to grow exponentially.

The furniture industry is the fastest growing sub-industry of the country’s timber industry, accounting for nearly 1.1% of Malaysia’s gross domestic product (GDP) [2]. The export of furniture accounts for 40% of the total export income of Malaysia's timber industry, and the furniture produced has spread all over the world [4]. The socio-economic importance of the industry is undeniable, bringing in nearly 18.4 billion US dollars in sales [3]. The export of furniture from Malaysia is dominated by wooden products, comprising around 70% of the total export figure [5]. Malaysia's wooden furniture industry faces considerable competition from Thailand, Indonesia, Vietnam, Taiwan and China in particular. As rival countries improve their production quality, Malaysia's furniture manufacturers and exporters are under increasing pressure to advance further.

For the industry to move up the value chain, it will focus on developing and expanding the required skills. Production and development skills include production management, maintenance, drawing and design, machine operation and finishing techniques. Due to occupational diseases, injuries, deaths, machine downtime, product defects and lack of motivation, worker productivity may be lost [6]. Hands-on training will be provided in specialized areas such as plantation management, advanced wood processing, and bio composite manufacturing, manufacturing and furniture design. The development of expertise in market and market intelligence will be given priority. Under the ASEAN Integration Initiative, the industry will be encouraged to use joint training and workshops to develop and improve the skills of the industry. Through the total factor productivity strategy, the productivity of the industry can be further improved. In the process of striving to move towards a higher value chain and improve productivity and quality, the industry will be encouraged to increase the utilization rate of automation equipment and machinery (including high-speed forming machines) to achieve higher mill efficiency and productivity and improve human capital quality. Cooperation with wood training centres and higher education institutions will help provide highly skilled labour. In labour planning, people are concerned with the description and prediction of the behaviour of large groups of people [7].

The world's demand for wooden furniture is increasing year by year. Therefore, many companies are involved in the production of high-quality wooden furniture. The highly competitive nature of the furniture market has led to more and more companies offering furniture customized according to end-user orders. In order to maintain a certain degree of standardization, these products are usually provided in the form of standard collections, with a limited number of attributes that end users of these collections can modify during the order specification stage. The wooden furniture industry lacks workers due to low wages and can get sick from dust and other diseases. The management must demonstrate a commitment to health and safety and incorporate safety precautions into the operating system to ensure a safe working environment in the wooden furniture manufacturing industry, which is very important [8]. People generally think that the safety environment in the wooden furniture industry is poor. This study shows that the current safety environment in woodworking factories depends on management and systems established to improve workplace safety and hygiene [9]. Therefore, the importance of finding workers in the furniture industry is very complicated. For example, XYZ factory requires an orderly manufacturing system to ensure the product is high quality and according to the specification set.

The optimal allocation of workers must be organized according to their respective expertise. Therefore, simulation is one of the solutions for modelling the manufacturing systems. Simulation is a useful and beneficial tool because it provides the best testing and training for manufacturing systems. It tends to be used in the industrial field to learn the behaviour of the system. Simulation provides companies with safe, low-cost, and fast analysis equipment. In the real world, testing and training are not easy, because it involves a lot of people and a lot of time, especially when the test fails to work and they encounter problems, they must run the test again. Through simulation, companies can identify and resolve errors before applying them to manufacturing system. Then, DEA-BCC can be used to determine the optimal worker allocation in the wooden furniture manufacturing system.

In the manufacturing system, whether as a new system or as an improvement to the previous system, it is best to model the wooden furniture manufacturing system. XYZ factory chooses to produce wooden furniture because its demand is increasing every year, so it is very important for the company to have an efficient manufacturing system. Operations that may require observation will involve high-level work. Many workers will lead to an increase in operating costs. Therefore, standard time refers to the amount of time that qualified workers should consider when using the given methods, tools and equipment, raw material input and workplace arrangements to complete a specific task at a sustainable speed. In addition, workers should be allocated according to the required number. The excessive number of workers at each station led to a decline in performance, wasted time, and the number of goods produced did not increase. In addition, the time it takes to complete certain products may affect the company's performance. The number of workers needs to be balanced, but if there are not enough workers, the production of furniture may be delayed. Therefore, it is important to analyze and understand all aspects involve in the process flow of the production process. Next, identify worker allocation alternatives. Finally, to suggest for improvement on optimal worker allocation in the wooden furniture manufacturing system.

The study involves the operating system and worker allocation in the XYZ factory, with a focus on the worker allocation to improve performance of the production process. Under the assumption that the system is stable, and the data collected in this study did not change during the study period. The simulation method, DEA-BCC and DEA-cross efficiency is used to determine the optimal worker allocation in the manufacturing system of the XYZ factory. The optimal worker allocation will improve the performance of the production process. This study helps and gives ideas and direction to the management of the wooden furniture manufacturing companies in determining the optimal worker allocation decision. In addition, the study can provide guidance to other researchers who are looking for methods to apply to related studies.

II. LITERATURE REVIEW

Simulation is usually a method of choice for problem solving. This is one of the most suitable methods for system analysis and performance evaluation to deal with many practical problems, because it has many variables, very complex and mathematically difficult to handle. Simulation can simulate and model any type of manufacturing system, whether it is a physical process, an information process, or a decision-making process. It can help in various fields such as design, management, decision-making, and production systems.

The main goal of any business, production or manufacturing company is to achieve and maintain its concurrency capabilities in the global market. This is only possible under the premise of continuously optimizing the working parameters and the internal organization of the production system to simultaneously increase production capacity, reduce production costs and maintain product quality. The simulation method does not disrupt the ongoing activities in the factory setting, but it provides a problem identification and resolution tool that is more flexible and less costly than physical prototyping and experimentation [10].

In the real world, the production process is complex and varied. Almost every manufacturing system and its production technology needs to change its target function. Although efforts are being made to standardize the work, even if the same product is produced in different locations, there will be a need for modification.

One of the key conditions for achieving a high performance of organization is the high performance of its own workers [11].

The interaction between system and worker should be considered [12]. Adding the extra workers or resources could cost more to the company as the resources may not function at full capacity [13]. The movement of workers from one workstation to another has a positive impact on the system’s worker satisfaction and productivity [14].

An important factor to be considered in the production system is the job rotation of workshop workers. It is also assumed that its implementation will improve work performance [15]. The movement of workers from one workstation to another has a positive impact on the system’s worker satisfaction and productivity.

The classical model is DEA-CCR model, as the method was extended in Banker *et al.* [16], known as DEA-BCC model. BCC approach also is a well-known method in evaluating performance. DEA model has been used to evaluate the efficiency and productivity in various industries such as healthcare [17], banking institution [18], manufacturing [19] and, schools and universities [20].

DEA helps to determine the efficiency of companies and be able to establish the production frontier [21] also claim that DEA model evaluates the relative efficiency which is the efficiency of each company with respect to other companies in the data set. Efficiency is related to the best practice, and it is evaluated using the benchmark or efficient frontier of the evaluated units. The DEA models use a set of decision-making units combining the multiple inputs and output variables to measure the relative efficiency.

DEA-Cross Efficiency is used to rank the efficient decision-making units (DMUs) or alternatives. It is based on the concepts of peer-to-peer evaluation and self-evaluation, which means that the efficiency of each DMU is calculated based on the weighted input and output used by other DMUs in the data set [22].

III. MATERIAL AND METHODS

The methodology in this study will be carried out in three phases. Figure 1 shows the research framework of the study.

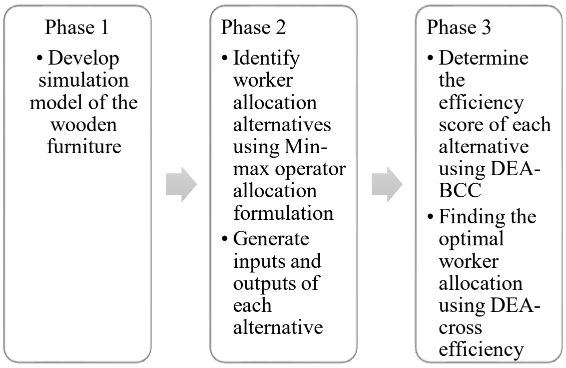

Fig.1. Research framework of the study.

The wooden furniture manufacturing system, namely XYZ factory located in Klang, Selangor is chosen in this study. The production line of wooden table has been divided into nine processes. The flow chart of the wooden table production process is shown in Fig. 2. First step in producing wooden table is material preparation from raw material storage to work area. Next is wood cutting to required sizes. After wood cutting is done, check if the size follows the specification, rubbing, and polishing. Then, joint and connection of wood is made. Initial inspection of wood for defects and repair, trimming if necessary and trimming and shaping area. Next, paint work area for colouring and coating with protective paints. After paint work area is done, the assembly process of wooden table is performed. Then, final inspection is done. The final process is packaging.

Currently, the total number of workers involved in the production process is 109. Eight workers to do the material preparation process, 12 workers handle the wood cutting process, 13 workers are required for size inspection, rubbing and polishing process and 14 workers are completed the joints and connection of wood process. Initial inspection, repair and trimming process are done by 13 workers, nine workers are required for colouring and coating process, 18 workers involve in the assembly process, final inspection process is done by 10 workers and 12 workers involve in the packaging process. Total production per day (11 hours) is 210 units of wooden tables.

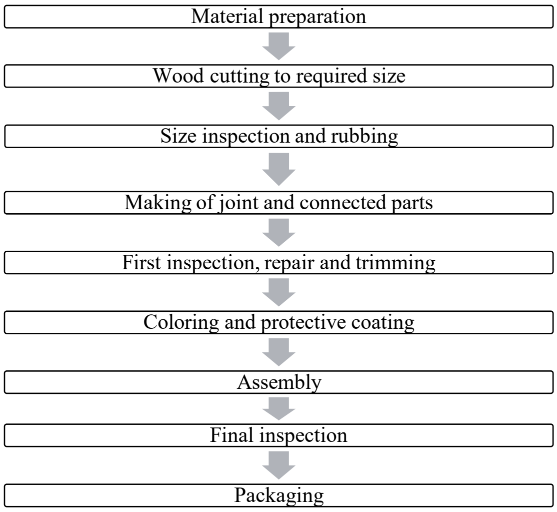

Fig. 2. The production process of wooden table (Source: XYZ factory).

After reviewing all the information needed in developing the simulation model, the essential data are the time between wood arrival, number of processes involved in the wooden table production process, the processing time at each process, number of workers at each process, number of productions per day and the operation hour per day. Primary data were collected during daily operation hours.

A. Phase 1: Develop the Simulation Model

Input analyzer is used to analyze the data to obtain the appropriate distribution. Input analyzer is a feature in Arena Software for fitting distribution from a sample data. All the distributions obtained from input analyzer are used in developing the simulation model. The expression and statistical distribution of the data for the actual system shown in Table I. The simulation model of the wooden table production line in Fig. 3 is developed using Arena 14.0 to visualize the existing production process.

Table I. Statistical distributions and expression of each processing time at each process.

Process	**Statistical Distribution**	**Expression**
Material Preparation	TRIANGULAR	TRIA (1.0,2.0,3.0)
Wood cutting	TRIANGULAR	TRIA (2.0,5.0,7.0)
Size Inspection and Rubbing	TRIANGULAR	TRIA (4.0,6.0,8.0)
Joints and Connection Part	TRIANGULAR	TRIA (3.0,4.5,6.0)
Initial Inspection, Repair and Trimming	TRIANGULAR	TRIA (4.0,5.0,6.0)
Coloring and Coating	TRIANGULAR	TRIA (20.0,25.0,30.0)
Assembly	TRIANGULAR	TRIA (15.0,17.5,20.0)
Final Inspection	TRIANGULAR	TRIA (10.0,12.5,15.0)
Packaging	TRIANGULAR	TRIA (5.0,7.5,10.0)

After developing the simulation model, next is to do model verification and model validation. Model verification shows the process of evaluating model operations. The verification process tests whether the model is functioning properly on the computer by using the correct data at the correct time. Common verification check was based on Little's Formula [23], which is given by Eq. (1).

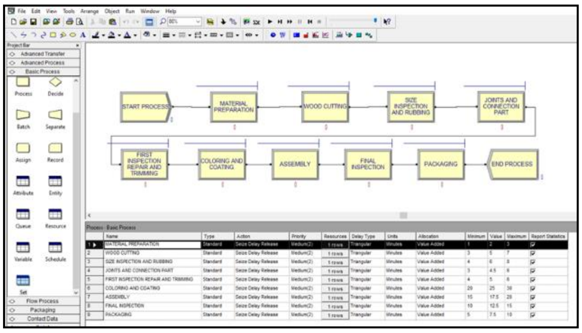

Fig. 3. Simulation model of Wooden Furniture Manufacturing System using Arena 14.0.

$$\overline{N} = \lambda\overline{W} \quad (1)$$

The simulation output will be used in calculating the values. The entity in this production process refers to a wooden table. $\overline{N}$ is the average number of wooden table in the system which is 225.21 units. $\lambda = 0.968$ is the average rate of arrivals into the system $\left(\lambda = \frac{639}{660}\right)$. $\overline{W}$= 263.90 minutes is the average time a wooden table spends in the system. $\lambda\overline{W}$ is therefore equals to 255.46, and therefore Eq. (1) is satisfied. Thus, the model is accepted as verified.

Model validation is the process of determining how the model captures and corresponds accurately to the actual system [24]. The simulation model runs in several replications and the differences between the simulation output and the actual data were compute using the following Eq. (2):

$$\text{Difference (\%)} = \frac{\text{Simulation Output} - \text{Actual Data}}{\text{Actual Data}} \text{ x } 100\% \quad (2)$$

In this study, the differences in values between the simulation output and actual data must be around ±10% or less, in order to satisfy the validity level of the built model to the actual system [25].

Table II shows the percentage of each process time, total number enter into the system and the total number out of the system. Since all values are not more than 10%, it shows that the model is valid.

Table II. The differences between simulation output and actual data.

Process	**Simulation output (minutes/ unit)**	**Actual data (minutes/ unit)**	**Differences (%)**
Material Preparation	1.9797	2.00	1.02
Wood cutting	4.9891	5.00	0.22
Size Inspection and Rubbing	5.9535	6.00	0.78
Joints and Connection Part	4.5141	4.50	0.31
First Inspection, Repair and Trimming	5.0060	5.00	0.12
Colouring and Coating	24.9023	25.00	0.39
Assembly	17.4854	17.50	0.08
Final Inspection	12.5462	12.50	0.37
Packaging	7.5378	7.50	0.50
Number In (units)	639	600	6.50
Number Out (units)	210	200	5.00

B. Phase 2a: Identify Worker Allocation Alternatives using Min-max Operator Allocation Formulation

After the simulation model is verified and validated, all possible worker allocation alternatives are identified. Worker allocation alternatives are identified based on the maximum and minimum number of workers required at each process. Table III shows the details regarding the minimum and maximum number of workers at each process.

Table III. Minimum and maximum number of workers required at each process.

Process	**Number of Workers**		
	Minimum	***Maximum***	***Actual system***
Material Preparation (i)	4	6	8
Wood cutting (j)	8	12	12
Size Inspection and Rubbing (k)		12	13
Joints and Connection Part (l)	10	12	14
First Inspection, Repair and Trimming (m)		14	13
Coloring and Coating (n)		9	9
Assembly (o)		20	18
Final Inspection (p)		12	10
Packaging (q)		12	12
Total number of operators		109	109

Min-max operator allocation formulation in Eq. (3) is used to identify all possible worker allocation alternatives [26].

$$\sum_i \sum_j \sum_k \sum_l \sum_m \sum_n \sum_o \sum_p \sum_q X_{(i,j,k,l,m,n,o,p,q)} = T \quad (3)$$

$T \leq S$
$X_y = 1$
$i = 4, \ldots, 8$
$j = 8, \ldots, 12$
$l = 10, \ldots, 12$
$k = 12, m = 14, n = 9, o = 20, p = 12, q = 12$
, where

i = The index for total workers at the material preparation
j = The index for total workers at the wood cutting
k = The index for total workers at the size inspection and rubbing

l = The index for total workers at the making joint and connect parts
m = The index for total workers at the initial inspection, repair, and trimming
n = The index for total workers at the coloring and protective coating
o = The index for total workers at the assembly
p = The index for total workers at final inspection
q = The index for total workers at the packaging
X = The workers allocation alternative
T = Number of workers
S = Maximum number of workers

Equation (3) is solved by Lingo 12.0 and 45 alternatives are identified. Table IV shows all 45 alternatives that has been identified.

Table IV. All 45 Worker allocation alternatives.

Alternatives	Process (Number of workers)									Total Number of Workers
	Material Preparation	*Wood cutting*	*Size Inspection & Rubbing*	*Joints & Connection Part*	*First Inspection, Repair and*	*Coloring & Coating*	*Assembly*	*Final Inspection*	*Packaging*	
A1	4	8	12	10	14	9	20	12	12	101
A2	4	8	12	11	14	9	20	12	12	102
A3	4	8	12	12	14	9	20	12	12	103
A4	4	9	12	10	14	9	20	12	12	102
A5	4	9	12	11	14	9	20	12	12	103
A6	4	9	12	12	14	9	20	12	12	104
A7	4	10	12	10	14	9	20	12	12	103
A8	4	10	12	11	14	9	20	12	12	104
A9	4	10	12	12	14	9	20	12	12	105
A10	4	11	12	10	14	9	20	12	12	104
A31	6	8	12	10	14	9	20	12	12	103
A32	6	8	12	11	14	9	20	12	12	104
A33	6	8	12	12	14	9	20	12	12	105
A34	6	9	12	10	14	9	20	12	12	104
A35	6	9	12	11	14	9	20	12	12	105
A36	6	9	12	12	14	9	20	12	12	106
A37	6	10	12	10	14	9	20	12	12	105
A38	6	10	12	11	14	9	20	12	12	106
A39	6	10	12	12	14	9	20	12	12	107
A40	6	11	12	10	14	9	20	12	12	106
A41	6	11	12	11	14	9	20	12	12	107
A42	6	11	12	12	14	9	20	12	12	108
A43	6	12	12	10	14	9	20	12	12	107
A44	6	12	12	11	14	9	20	12	12	108
A45	6	12	12	12	14	9	20	12	12	109
Actual system	8	12	13	14	13	9	18	10	12	109

C. *Phase 2b: Generate Inputs and Outputs of Each Alternative*

In generating inputs and outputs of each alternative, all 45 alternatives in Table IV which represent 45 simulation models are run using Arena 14.0. The selection of inputs and outputs are based on previous studies. The inputs selected are number of entities in the system (v1), number of entities still in progress (v2), the average total waiting time per entity (v3), the average total production time per entity (v4), while the selected outputs are the average worker utilization (u1) and the total production per day (u2). The inputs and outputs of 45 worker allocation alternatives are gathered and shown in Table V.

Table V. The inputs and outputs of 45 worker allocation alternatives.

Alternative	Input				Output	
	Number in, v1 (units)	*Work in Progress, v2 (units)*	*Average Total Waiting Time, v3 (minutes)*	*Average Total Production Time, v4 (minutes)*	*Average Worker Utilization, u1*	*Total Production, u2 (units)*
A1	653	234.54	189.2785	274.0413	0.4245	212
A2	672	249.34	189.9200	274.9474	0.4247	212
A3	672	249.34	189.9200	274.9474	0.4196	212
A4	691	252.22	194.3600	279.1528	0.4331	213
A5	691	252.22	194.3600	271.4140	0.4289	213
A6	691	252.22	194.3600	279.1528	0.4248	213
A7	654	224.37	171.7800	256.6899	0.4154	210
A8	644	226.51	181.7800	266.6395	0.3987	211
A9	644	226.51	181.7800	266.6395	0.3987	211
A10	659	238.63	188.7400	273.8843	0.3987	210
A11	671	237.96	191.0300	275.4970	0.4158	214
A12	671	237.96	191.0300	275.4970	0.4119	214
A13	670	248.03	192.1500	277.2030	0.4147	209
A14	650	234.37	190.0600	274.4697	0.4051	214
A15	650	234.37	190.0600	274.4697	0.4013	214
A16	671	227.30	180.2100	264.8394	0.4258	211
A17	671	243.38	184.9000	269.8299	0.4175	211
A18	671	243.38	184.9000	269.8299	0.4181	211
A19	666	245.52	185.8200	270.5089	0.4217	211
A20	643	224.01	186.3100	271.0879	0.4006	210
A21	636	233.33	185.2600	269.9177	0.4052	213
A22	639	226.04	180.3500	265.2141	0.4079	210
A23	658	234.08	182.3600	267.2084	0.4130	210
A24	658	234.08	182.3600	267.2084	0.4087	210
A25	688	258.69	195.8400	280.7480	0.4200	211
A26	732	269.70	193.3100	278.1649	0.4297	209
A27	738	269.73	193.3100	278.1470	0.4261	208
A28	688	247.81	186.3500	271.0293	0.4164	211
A29	632	219.42	180.8500	265.7057	0.3964	212
A30	678	251.54	191.5000	276.3718	0.4052	211
A31	630	221.16	189.7700	274.8397	0.4074	210
A32	627	219.68	188.8300	274.0078	0.4028	210
A33	627	219.68	188.8300	274.0078	0.3999	210
A34	666	237.98	189.2800	274.0278	0.4151	211
A35	678	242.95	191.1900	276.1643	0.4142	209
A36	670	238.78	184.8300	269.6515	0.4101	211
A37	675	230.23	181.3600	265.8707	0.4172	212
A38	688	258.45	193.0700	277.9508	0.4149	210
A39	662	239.38	192.6100	277.6357	0.4038	209
A40	632	223.48	193.1600	277.8302	0.3982	211
A41	633	233.82	186.9400	271.7030	0.3931	210
A42	633	233.82	186.9400	271.7030	0.3894	210
A43	640	234.32	193.6600	278.3620	0.3972	212
A44	673	248.72	197.1900	282.2375	0.4024	208
A45	673	248.72	197.1900	282.2375	0.3987	208
Actual system	639	225.00	191.1680	276.0741	0.3900	210

D. *Phase 3a: Determine the Efficiency Score of Each Alternative using DEA-BCC*

The efficiency scores are determined using DEA-BCC model introduced by Banker *et al.* [16]. The model is output oriented is a measure efficiency to reach a maximum level of outputs to the given inputs. The DEA-BCC model used is as follows:

$$\theta_0 = min\sum_{i=1}^{m} v_i\, x_{ik_0} - v_0$$

Subject to (4)

$$\sum_{j=1}^{n} u_j y_{jk_0} = 1, \quad \sum_{i=1}^{m} v_i\, x_{ik} - \sum_{j=1}^{n} u_j\, y_{jk} - v_0 \geq 0$$

$$i = 1,\dots,m, \quad j = 1,\dots,n, \quad k = 1,\dots,s, \quad u_j, v_i \geq \varepsilon$$

, where u_0 is unconstrained in sign, θ_0 is relative efficiency for Alternative0 or DMU0, y_{jk_0} is total output *j* from unit k_0, y_{jk} is total output *j* from unit *k*, x_{ik_0} is total input *i* from unit k_0, x_{ik} is total input *i* from unit *k*, u_j is the weight given to output *j*, v_i is the weight given to input *i*, *n* is the output number, *m* is the input number, and ε is a small positive number. DMU0 is efficient if $\theta_0 = 1$ or $\frac{1}{\theta_0} = 1$, DMU0 is not efficient if $\frac{1}{\theta_0} < 1$. However, when using the DEA-BCC model, there is a possibility of acquiring more than one efficient DMU. DEA-BCC model in Eq. (4) then is solved using Lingo 12.0. Table VI shows the efficiency scores of each alternative.

Based on Table VI shows the efficiency scores of A1, A7, A16, A21, Al22, A29, A31, A32, and A33 are equal to one. Alternatives are efficient if $\theta_0 = 1$ or $\frac{1}{\theta_0} = 1$. The efficient alternatives will be ranked using DEA-cross efficiency.

Table VI. The efficiency scores of 45 worker allocation alternatives.

DMU	Score, θ	1/θ	DMU	Score, θ	1/θ
A1	1.0000	1.0000	A24	1.0245	0.9760
A2	1.0210	0.9794	A25	1.0562	0.9468
A3	1.0301	0.9708	A26	1.0542	0.9486
A4	1.0255	0.9752	A27	1.0635	0.9403
A5	1.0267	0.9740	A28	1.0508	0.9516
A6	1.0451	0.9569	A29	1.0000	1.0000
A7	1.0000	1.0000	A30	1.0586	0.9447
A8	1.0143	0.9859	A31	1.0000	1.0000
A9	1.0142	0.9860	A32	1.0000	1.0000
A10	1.0441	0.9578	A33	1.0000	1.0000
A11	1.0291	0.9717	A34	1.0296	0.9712
A12	1.0335	0.9676	A35	1.0515	0.9510
A13	1.0432	0.9586	A36	1.0360	0.9653
A14	1.0171	0.9832	A37	1.0205	0.9799
A15	1.0198	0.9806	A38	1.0629	0.9409
A16	1.0000	1.0000	A39	1.0487	0.9536
A17	1.0286	0.9722	A40	1.0062	0.9938
A18	1.0278	0.9730	A41	1.0079	0.9922
A19	1.0164	0.9838	A42	1.0079	0.9922
A20	1.0190	0.9814	A43	1.0156	0.9847
A21	1.0000	1.0000	A44	1.0712	0.9336
A22	1.0000	1.0000	A45	1.0765	0.9289
A23	1.0187	0.9816			

E. Phase 3b: Finding the Optimal Worker Allocation using DEA-Cross Efficiency

There is a chance to get more than one efficient DMU by using DEA-BCC model. In that case, DEA-cross efficiency is used to rank the DMUs. DEA-cross efficiency is developed by Sexton *et al.* [27]. The DEA-cross efficiency of the DEA-BCC output-oriented model is calculated using Eq. (5).

$$E_{j0} = \frac{\sum_{i=1}^{m} v_{i0} x_{ij} - v_0}{\sum_{r=1}^{s} u_{r0} y_{rj}} \qquad i = 1, \dots, m, \quad r = 1, \dots, s \tag{5}$$

$$\bar{E}_0 = \frac{\sum_{j=1}^{n} E_{i0}}{n} \qquad j = 1, \dots, n$$

, where E_{j_0} is the score for DMU*j* using optimal weights selected by DMU0. $\bar{E}_0$ is the average efficiency score given to DMU0. The DMU's with the lowest $\bar{E}_0$ will be in the first ranked. Table VII shows the DEA-cross efficiency matrix of the efficient DMUs.

Table VII. DEA-cross efficiency matrix.

DMUs	A1	A7	A16	A21	A22
A1	1.3739	1.3820	1.3883	1.4022	1.3917
A7	1.0281	1.0000	1.0000	1.0437	1.0172
A16	1.0279	1.0010	1.0000	1.0451	1.0181
A21	1.0000	1.0000	1.0113	1.0000	1.0011
A22	0.9963	1.0085	1.0192	0.9932	0.9988
A29	1.0561	1.0000	1.0244	1.0369	1.0236
A31	1.0000	1.0164	1.0217	1.0105	1.0109
A32	1.0281	1.0011	1.0000	1.0453	1.0182
A33	1.5151	1.5272	1.5598	1.4696	1.4956
Average efficiency score	1.1139	1.1040	1.1138	1.1163	1.1084
Rank	8	5	7	9	6

DMUs	A29	A31	A32	A33
A1	1.4182	1.3893	1.3981	1.4080
A7	1.0009	1.0005	1.0000	1.0038
A16	1.0022	1.0002	1.0000	1.0040
A21	1.0039	1.0001	1.0019	1.0058
A22	0.9982	0.9880	0.9891	0.9929
A29	1.0000	1.0355	1.0296	1.0296
A31	1.0208	1.0000	1.0042	1.0100
A32	1.0023	1.0002	1.0000	1.0040
A33	1.4654	1.4769	1.4698	1.4698
Average efficiency score	1.1013	1.0990	1.0992	1.1031
Rank	3	1	2	4

Based on DEA-cross efficiency matrix in Table VII, the average efficiency score of A31 is the lowest which is 1.0990. It means that A31 is in the first rank followed by A32, A29, A33, A7, A22, A16, A1, and A9, respectively. Therefore, A31 is considered as the best alternative or optimal worker allocation alternative among 45 alternatives. Based on finding in Phase 3b, this study has suggested Alternative-31 (A31) is the best alternative among 45 alternatives. The comparison of inputs, outputs, and total number of workers between the actual system and A31 is shown in Table VIII. The advantages of A31 are the average total waiting time and the average total production time are decreased compared to the actual system. A31 can produce the same number of wooden tables as the actual system but reduces the number of entities that are still in the system by 1.71%. The average worker utilization is increased by 4.46% for this new worker allocation alternative. Compared with the actual system, the total number of workers is reduced the total number of workers from 109 to 103 and the average waiting time in minutes required at the four processes from 191.1680 to 189.7700. Therefore, A31 is chosen as the best alternative because the modifications can improve the actual system.

Table VIII. Inputs, outputs and total number of workers of the actual system and A31.

Model	Input				Output		Total number of workers
	Number In (units)	*Work in Progress (units)*	*Average Total Waiting Time (minutes)*	*Average Total Production Time (minutes)*	*Average Worker Utilization*	*Total Production (units)*	
Actual System	639	225.00	191.1680	276.0741	0.3900	210	109
A31	630	221.16	189.7700	274.8397	0.4074	210	103
Difference (%)	1.41	1.71	0.73	0.45	4.46	0.00	5.50

IV. CONCLUSIONS AND RECOMMENDATIONS

In this study, combination of simulation method, DEA-BCC and DEA-cross efficiency are used to determine the optimal worker allocation. Min-max operator allocation formulation is used to identify the worker allocation alternatives. Then, simulation method is used to generate inputs and outputs of various worker allocation alternatives. Next, DEA-BCC is used to determine the efficiency score of each alternative and to rank the alternative, DEA-cross efficiency is applied. The first ranked alternative will be the best alternative. The results of the best alternative are compared with the actual system. The results attained indicate that the optimal worker allocation alternative is the best in terms of inputs, outputs obtain, and total number of workers involved. For future improvement of this study, different approaches can be employed. The other inputs and outputs will be identified and included of each worker allocation in a way to get more relevant results.

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AUTHOR CONTRIBUTIONS

Ruzanita Mat Rani: Designed the study. Developed the methodology and data analysis.

Nurul Hidayah Radzwan: Data collection and data analysis. Writing and review the manuscript.

Wan Laailatul Hanim Mat Desa: Model verification and model validation. Data analysis.

Rosmaini Kashim: Writing and review the manuscript.

CONFLICT OF INTERESTS

No conflict of interests.

ETHICS STATEMENTS

The ethical approval was obtained from UiTM Research Ethic Committee [Ref. no. 100-KPPIM (PI.9/10/) (MR/949)].

REFERENCES

[1] J. Ratnasingam, K. A. Chin, H. Abdul Latib, H. Subramaniam and A. Khoo, "Innovation in The Malaysian Furniture Industry: Drivers and Challenges," *BioResources.* vol. 13, no. 3, pp. 5254-5270, 2018.

[2] J. Ratnasingam, "The Malaysian Furniture Industry: Charting Its Growth Potential," Inaugural Lecture, Universiti Putra Malaysia, 7 April 2017.

[3] "Malaysian International Furniture Fair 2024," [Available online on 4 April 2024] https://miff.com.my/malaysian-furniture-industry/.

[4] "Malaysian Investment Development Authority," *e-Newsletter*, December 2021, [Available online on 4 April 2024] https://www.mida.gov.my/wp-content/uploads/2022/01/MIDA-Newsletter-Dec-2021.pdf.

[5] "Malaysian Timber Council Annual Report 2020," [Available online on 4 April 2024] https://mtc.com.my/images/publication/229/MTC_2020_Annual_Report_Final_Spread.pdf.

[6] J. E. Dodoo and H. Al-Samarraie, "A Systematic Review of Factors Leading to Occupational Injuries and Fatalities," *J. Publ. Health,* vol. 31, no. 1, pp. 99–113, 2023.

[7] F. Green and G. Henseke, "Europe's Evolving Graduate Labour Markets: Supply, Demand, Underemployment and Pay," *J. Labour Mark. Res.,* vol. *55*, no.1, pp. 2, 2021.

[8] A. Colim, A. Cardoso, S. Martins, J. Mano, P. Carneiro and P. Arezes, "Safety Culture and Risk Perception in A Furniture Manufacturing Company – A Case Study," in *Int. Conf. Appl. Hum. Fact. and Ergonom.*, Cham: Springer International Publishing, pp. 311-318, 2021.

[9] H. Grace, "*Back to Basics: Woodworking Safety*," EHS Daily Advisor. [Available online on 4 April 2024] https://ehsleaders.org/2022/10/back-to-basics-woodworking safety/.

[10] W. R. Nyemba and C. Mbohwa, "Modelling, Simulation and Optimization of The Materials Flow of A Multi-Product Assembling Plant," *Proc. Manufact.,* vol. 8, pp. 59-66, 2017.

[11] F. Flood and M. Klausner, "High-Performance Work Teams and Organizations," *Global Encyclopedia of Public Administration, Public Policy, and Governance*, Cham: Springer International Publishing, pp. 6189-6194, 2023.

[12] V. E. Prasetyo, B. Belleville and B. Ozarska, "A Proposed Method and Its Development for Wood Recovery Assessment in the Furniture Manufacturing Process," *BioResources,* vol. 13, no. 2, pp. 3846-3867, 2018.

[13] M. Subramaniyan, A. Skoogh, M. Gopalakrishnan, H. Salomonsson, A. Hanna and D. Lämkull, "An Algorithm for Data-driven Shifting Bottleneck Detection," *Cogent Eng.*, vol. 3, no. 1, pp. 1239516, 2016.

[14] I. S. Jeon and B. Y. Jeong, "Effect of Job Rotation Types on Productivity, Accident Rate, and Satisfaction in The Automotive Assembly Line Workers," *Hum. Fact. and Ergonom. in Manufact. & Serv. Indust.,* vol. 26, no. 4, pp. 455-462, 2016.

[15] A. Ogbeyemi, W. Lin, F. Zhang and W. Zhang, "Human Factors Among Workers in A Small Manufacturing Enterprise: A Case Study," *Enterpr. Informat. Syst.*, vol. 15, no. 6, pp. 888–908, 2021.

[16] A. R. D. Banker, A. Charnes and W. W. Cooper, "Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis Stable," *Manage. Sci.,* vol. 30, no. 9, pp. 1078-1092, 1984.

[17] V. J. M. Cantor and K. L. Poh, "Integrated Analysis of Healthcare Efficiency: A Systematic Review," *J. Medic. Syst.,* vol. 42, no. 81, pp. 8, 2018.

[18] H. Wu, J. Yang and W. Wu, "Interest Rate Liberalization and Bank Efficiency: A DEA Analysis of Chinese Commercial

Banks," *Centr. Europ. J. Operat. Res.,* vol. 31, no. 2, pp. 467–498, 2023.

[19] Z. Shen and X. Zhao, "Evaluation of Resource Utilization Efficiency in the Machining Process Based on the SBM-DEA Model with Non-Expected Output," *Processes,* vol. 11, no. 3, pp. 916, 2023.

[20] U. Mahmudah and M. S. Lola, "The Efficiency Measurement of Indonesian Universities Based on a Fuzzy Data Envelopment Analysis," *Open J. Statist.,* vol. 6, no. 6, pp. 1050-1066, 2016.

[21] J. Titko, J. Stankevičienė and N. Lāce, "Measuring Bank Efficiency: DEA Application," *Technol. and Econ. Develop. Econ.*, vol. 20, no. 4, pp. 739-757, 2014.

[22] A. Aldamak and S. Zolfaghari, "Review of Efficiency Ranking Methods in Data Envelopment Analysis," *Measurement,* vol. 106, pp. 161-172, 2017.

[23] T. Altiok and B. Melamed, "Simulation Modeling and Analysis with Arena," Elsevier, 2007.

[24] J. Banks, J. S. Carson, B. L. Nelson and D. M. Nicol, "Discrete-Event System Simulation," 5th Edn, Pearson Education, 2010.

[25] R. M. Tahar, "A Practical Approach to Computer Simulation Modelling," Universiti Putra Malaysia Press, 2006.

[26] M. R. Ruzanita Mat Rani, "Kaedah Tiga Fasa bagi Menentukan Alternatif Pengagihan Operator yang Optimum," *Tesis Doktor Falsafah*, Universiti Kebangsaan Malaysia, 2017.

[27] T. R. Sexton, R. H. Silkman and A. J. Hogan, "Data Envelopment Analysis: Critique and Extensions," *New Direct. Progr. Evaluat.,* vol. 32, pp. 73-105, 1986.