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Assembly Line Balancing using Artificial Neural Network: A Case Study of Tricycle Assembly Line

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Abstract
This study reports the use of Artificial Neural Network in balancing an existing single-model assembly line of Boulous Enterprises Limited. A multilayer perceptron, with the help of online training was utilized, due to its ability to accommodate large dataset. The results obtained showed that standard cycle time of 576 seconds in the existing line was reduced to 526 seconds. Also, the average idle time was reduced from 105 seconds to 56 seconds, and the output of tricycles produced per day was increased from 50 to 55. The results clearly showed that a better balanced line was obtained with the use of Artificial Neural Network.
Keywords: Line Balancing, bottlenecks, Idle Time, Efficiency

1. Introduction

The quality of a product and its capability to meet customers' demands are important aspects that should not be neglected and also to be accounted for, especially in small and medium scale industries. Companies must realise that their performance is dependent on how well the production line flows, in terms of product output. The adoption of assembly line balancing in the evolution of manufacturing is highly essential. Generally, assembly line is a manufacturing process where the bill-of-material parts and components are attached in arranged order to a unit by a series of workers to create a semi-finished product. Assembly line balancing can also be loosely defined as the process of allocating a group of tasks to be performed sequentially, in such a manner that all workstations have approximately equal amount of assigned workloads, in order to optimize the measure of performance, that is, minimize time, bottlenecks and cost, with an increased rate of product output. For instance, a car company might want to alter its assembly line layout in order to speed the rate of production, the company then considers the number of workstations a manufactured item will or must pass before it is complete and the time required at each point of course. Assembly line balancing can also guide in decision making based on the multitude of variables that can affect the manufacturing process.

A company balancing unique workloads must work within the constraints and restrictions affecting its assembly line. To optimize very specific operations, balancing an assembly line might require different methods, some of which includes; Genetic Algorithm, Heuristic Approach, Simulation Techniques, Ant Colony Optimization (ACO) etc; but in this study, we are applying Artificial Neural Network (ANN).

Recently researchers have focused their attention in using computer based techniques for balancing assembly lines. In order to achieve the aim of minimizing the overall length of a line and provide a near optimal solution in real time, Yeokeun et al. (1995) studied sequencing in mixed model assembly lines using a Genetic Algorithm (GA) approach. A new genetic operator, immediate successor relation crossover (ISRX) was introduced and an extensive experiment was carried out, and the Genetic Algorithm compared with heuristic algorithms and other methods was proven to have a better performance. The results showed that Genetic Algorithm greatly reduces the computation time and its solution was very close to the optimal solution.

Moreover, with the aim of maximizing workload smoothness and distributing the workload evenly to the workstation in an assembly line Yong-Ju et al. (1998) presented a heuristic based genetic algorithm for workload smoothing in assembly lines, by using a new heuristic procedure based on genetic algorithm to balance the assembly line. The results established a sense of equity among workers, increased output and improved cycle time. To improve the piston assembly line, Xiao-Feng et al. (2010) used machine vision recognition technology (MVRT) with the aim of improving the quality of piston assembling and reduce labour intensity which resulted to an improved quality and the problems of missed assembling, reversed assembling, and mixed assembling due to workers operation errors were minimized.

Abhiram and Emre (2011) also made use of Hierarchical Task Analysis and Dynamo tools with the aim of defining the complexity of a production system and help manage it. In their analysis, they found out that by reducing the number of components or the number of base models will lead to lower buffers, lower level of inventory and will move forward in a direction of less complex product. Miceita and Stollman (2011) applied the Ant colony optimization (ACO) approach to assembly line balancing algorithm with the aim of minimizing the number of workstations. The procedure minimized the number of workstations as their major goal.

Genetic Algorithm has been combined with topological sort procedure for solving assembly line balancing problem (Norain, 2010). The study aimed at minimizing the total idle time in the workstation. From the analysis, the presented combined approach was seen as the ideal compromise of optimizing complex and large problems and is thus highly recommendable for practical approach. Siddesh et al. (2013) adopted the Line of Balancing Scheduling Technique (LOBST) aimed at improving the line of balancing concepts on building and construction. It was found that LOBST played a major role in facilitating the implementation of building information modelling technologies. In solving line balancing in a cashew nut shelling machine production, Santosh and Suresh (2013) used the ranked position weight (RPW) method with the main purpose of developing the assembly line and balancing it. It was found that RPW method is useful when less data is available.

Most recent techniques include the use of artificial intelligence methods for balancing assembly lines. Mithilesh and Zadgaonkar (2012) used the Artificial Neural Network (ANN) to measure on-line voltage disturbances. The results obtained showed that the computational time is nearly instantaneous. This shows that ANN can be a very useful technique in balancing assembly lines. Artificial Neural Network is a computing system made up of a number of simple, highly inter-connected processing elements, which process information by their dynamic state and response to external inputs (Robert, 1989). Artificial Neural Network (ANN) is a recent development established before the advent of computers, the first artificial neuron was produced by the Neurophysiologists and the Logician, (Warren and Walter, 1943). ANN, with their remarkable ability to derive meaning from complicated or imprecise data can be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computer techniques.

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2. Methodology

2.1 Primary Data

The primary data for this study were collected from the tricycle assembly line of Boulous Enterprises Limited, for fifteen (15) days. Table 1 below shows the task or operation performed and the time in seconds in the assembling of each tricycle.

2.2 Secondary Data

Required Output per day = 50tricycles per day
Available time per day = 8 hours
= 480 mins.
= 28800 seconds
Number of workstations = 8
Cycle time = 576seconds

2.3 Cycle Time

The cycle time is determined by means of demand rate of the product (s) in a planning horizon. Mathematically,

$$Cycle\ time = \frac{Available\ Production\ Time\ Per\ Day}{desired\ Number\ of\ Units\ Per\ Day} \quad [1]$$

The cycle time in most cases is referred to as Takt time.

2.4 Theoretical number of workstations

Mathematically,

$$Theoretical\ number\ of\ workstation = \frac{Total\ task\ time}{Cycle\ Time} \quad [2]$$

2.5 Efficiency

The efficiency or utilization of an assembly line is the percentage of time a production line is working. Mathematically,

$$Efficiency = \frac{Sum\ of\ Task\ Times}{Cycle\ Time\ x\ Number\ of\ Actual\ Workstations}\% \quad [3]$$

2.6 Precedence Diagram

The precedence diagram defines relationship between the activities/tasks, displaying the order in which the activities are to be done. Figure 1 below shows the precedence diagram.

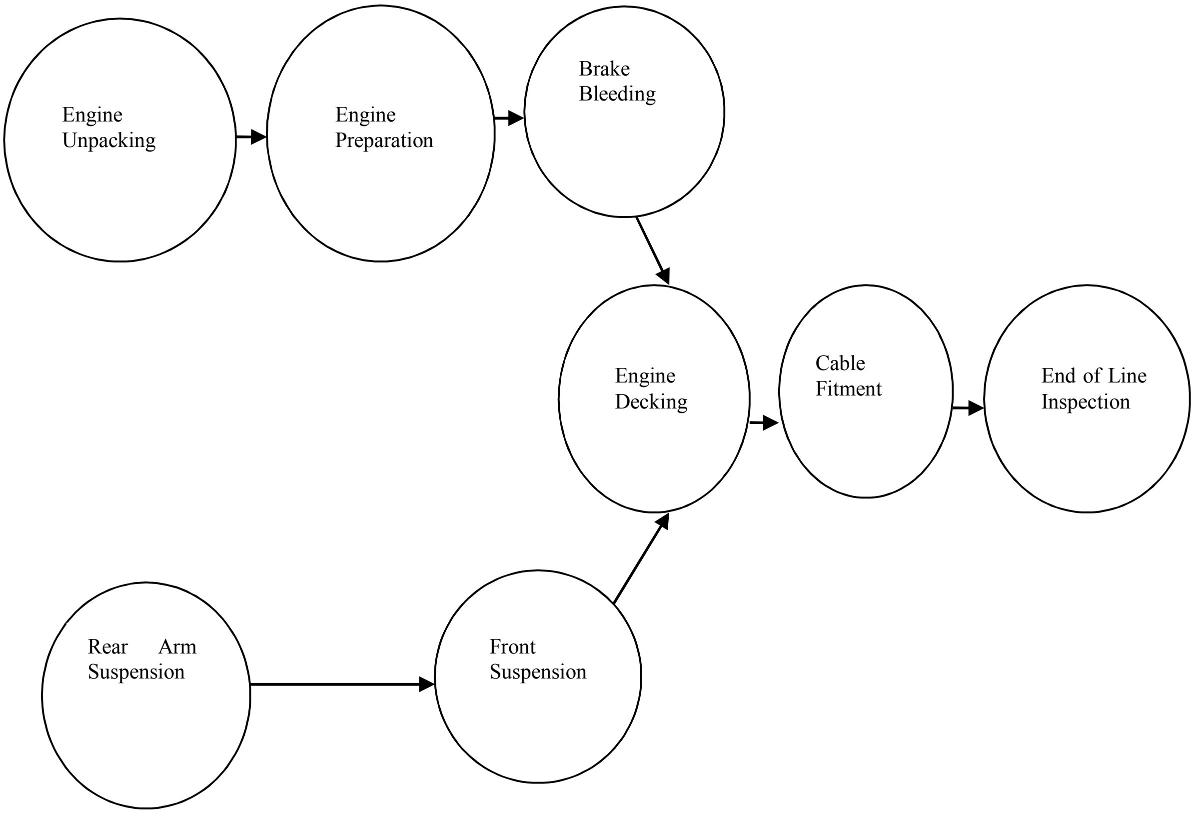

Fig. 1: Precedence diagram of the assembly line

2.7 Workstation balancing

In workstation balancing, tasks are grouped together following the order of precedence and as a rule; each workstation time should not exceed the cycle time specified. The raw data from the tricycle assembly line were originally grouped into eight (8) workstations as shown in table 1 below.

Table 1. Eight Workstation data

TIME TAKEN IN EACH WORKSTATION FOR 15 DAYS								
NO OF TRICYCLES / WORKSTATION	ENGINE UNPACKING (SEC)	ENGINE PREPARATION (SEC)	REAR ARM SUSPENSION (SEC)	FRONT SUSPENSION (SEC)	BRAKE BLEEDING (SEC)	ENGINE DECKING (SEC)	CABLE FITMENT (SEC)	END OF LINE INSPECTION (SEC)
1	32	390	707	1445	394	283	592	392
2	23	465	674	1308	354	344	552	310
3	34	433	619	1462	353	259	664	312
4	35	474	683	1427	393	243	635	346
5	30	431	683	1306	379	291	633	314
6	25	416	614	1297	390	320	590	326
7	30	459	615	1265	382	275	670	368
8	31	464	657	1400	380	283	583	350
9	25	422	634	1369	346	296	638	309
10	23	420	542	1371	383	279	612	323
11	29	448	642	1415	374	285	564	318
12	27	447	624	1345	385	287	613	369
13	27	456	548	1424	385	255	544	321
14	34	439	580	1320	357	284	556	326
15	30	393	622	1272	365	249	642	324

From table 1 above, REAR ARM SUSPENSION, FRONT SUSPENSION and CABLE FITMENT are the workstations with the highest time along each row.

2.8 Minimizing Number of Workstation

In minimizing the number of workstation, there are two algorithms that can be employed. The algorithms are explained below.

2.9 Weighted Average Balance

The weighted average balance considers the weighted times of the different task or activities and ensures that they are within the takt time specified. The weighted average balance is applicable only for mixed model balancing.

2.10 Peak Model Balance

The peak model balance or the conservative balance checks to make sure that the model with the highest time is below the takt time specified. By locating the model with the highest time, we ensure that none of the models exceed the takt time in a given workstation.

2.11 Minimizing Cycle Time

This is a balancing method where the desired number of workstation is specified. The workstation is balanced by minimizing the Takt time for the available list of tasks while ensuring that the precedence relationship is maintained.

2.12 Multilayer Perceptron Neural Network Algorithm (MLP)

The multilayer perception neural network algorithm (MLP) was used in the study.

2.13 Training

The network was trained based on the data specified in the input (that is, the thirty six (36) tasks performed in the assembly of a tricycle) and output layer (containing the output takt time). The type of training and the optimization algorithm determines which training options are available as the training type determines how the network processes the records. Online training can more quickly obtain a reasonable answer than batch training. In this study, the online training was used in training the network as the inputs in the dataset are large.

3. **Results and Discussion**

3.1 Workstation Balance Performance

For this assembly line, 576 seconds is the amount of time required to complete work at each station. The various tasks performed in the 8 workstations are shown below.

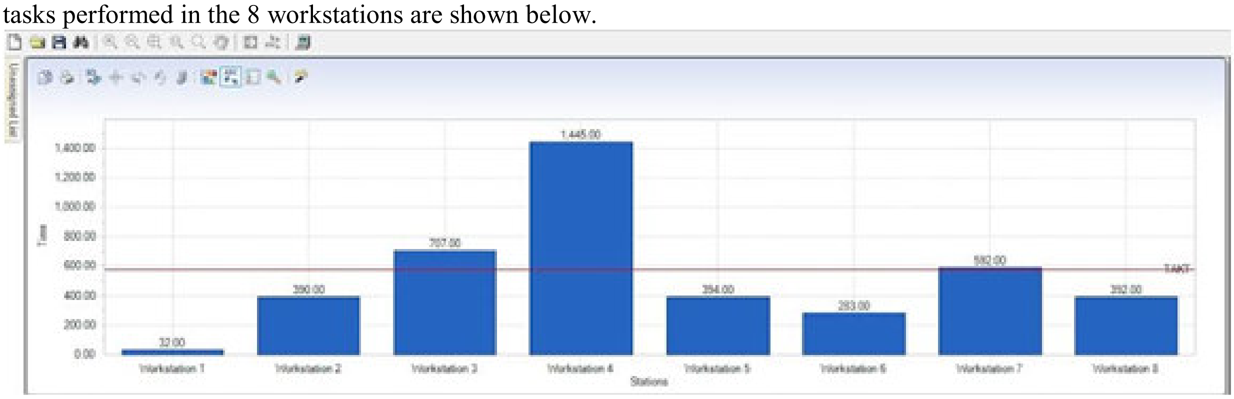

Figure 2: Station line view with a cycle time of 576seconds *(using MATLAB software)*

The various tasks to be performed were re–arranged and grouped into nine workstations. The station line view for the nine workstations is shown below.

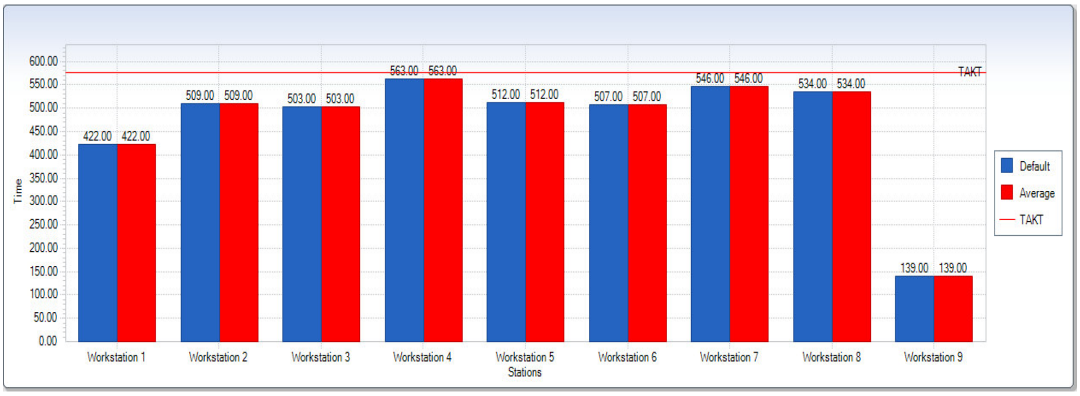

Figure 3: Station line view with a takt time of 576seconds

Allocating one operator to each workstation, the station balance details is shown in Table 2 below. For *tricycle* 1, the total time spent was 4235seconds

Table 2. Station Balance Report grouping task into stations

Takt Time:	576 sec.				
Total Line Time:	4235 sec.				
	Maximum	Minimum		Average	
Station Time (Sec.)	563	139		470.56	
Idle Time (Sec.)	437	13		105.44	
Utilization (%)	98.00	24.00		82.00	
Workstation	Avg. Wt. Time (secs)	Avg. Time (secs)	Avg. Utilization (%)	No. of Operators	Avg. Idle Time (secs)
Workstation 1	422	422	73	1	154
Workstation 2	509	509	88	1	67
Workstation 3	503	503	87	1	73
Workstation 4	563	563	98	1	13
Workstation 5	512	512	89	1	89
Workstation 6	507	507	88	1	69
Workstation 7	546	546	95	1	30
Workstation 8	534	534	93	1	42
Workstation 9	139	139	24	1	437

The table above shows the balance reports of the nine (9) workstations and it was seen that the station with the maximum station time was workstation 4 i.e. 563seconds with an idle time of 13seconds, while workstation 9 has the minimum station time of 139seconds and idle time of 437seconds. For the nine workstations, the average station time was 470.56seconds, an average idle time of 105.44second with an average utilization of 82%. The various tasks in the nine workstations are listed in the table 3 below.

Table 3. List of tasks in the nine workstations

Station ID: Workstation 1

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T1	Engine Unpacking	32.00	1.00	32.00								
	T2	Exhaust / Muffler Fitment	138.00	1.00	138.00								
1	T3	Drive Shaft Fitment	91.00	1.00	91.00								
1	T4	Air Box Fitment	62.00	1.00	62.00								
1	T5	Front Cross Member	61.00	1.00	61.00								
1	T6	Gear Oil	38.00	1.00	38.00								
		Total:	422.00 Sec.										

Station ID: Workstation 2

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T7	Chassis Preparation	218.00	1.00	218.00								
1	T8	Rear Suspension Fitment	109.00	1.00	109.00								
1	T9	Brake Hose Fitment	109.00	1.00	109.00								
1	T10	Shock Absorber	73.00	1.00	73.00								
Total: 509.00 Sec.													

Station ID: Workstation 3

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T11	Hand Brake Cable Fitment	140.00	1.00	140.00								
1	T12	Hand Brake Drum Fitment	58.00	1.00	58.00								
1	T13	Repositioning of Chassis	139.00	1.00	139.00								
1	T14	Packaging Back Frame	166.00	1.00	166.00								
Total: 503.00 Sec.													

Station ID: Workstation 4

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T15	Head Lamp Fitment LHS	87.00	1.00	87.00								
1	T16	Head Lamp Fitment RHS	73.00	1.00	73.00								
1	T17	Front - Suspension -1	274.00	1.00	274.00								
1	T18	Front - Suspension -2	129.00	1.00	129.00								
Total: 563.00 Sec.													

Station ID: Workstation 5

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T19	Head Lamp Fitment -3	123.00	1.00	123.00								
1	T20	Front Brake Hose Connection	65.00	1.00	65.00								
1	T21	Rear Tyre Fitment	301.00	1.00	301.00								
1	T22	Horn	23.00	1.00	23.00								
Total: 512.00 Sec.													

Station ID: Workstation 6

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T27	Engine Chassis Feeding	48.00	1.00	48.00								
1	T23	Handle Bar	65.00	1.00	65.00								
1	T24	Brake Fluid Topping & Bleeding	113.00	1.00	113.00								
1	T25	Brake Fluid Topping & Bleeding	140.00	1.00	140.00								
1	T26	Brake Fluid Topping & Bleeding	141.00	1.00	141.00								
Total: 507.00 Sec.													

Station ID: Workstation 7

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Wor Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T30	Control Cable Fitment1	169.00	1.00	169.00								
	T31	Control Cable Fitment 2	142.00	1.00	142.00								
1	T28	Rear Arm To Frame	111.00	1.00	111.00								
1	T29	Drive Shaft Fitment	124.00	1.00	124.00								
Total: 546.00 Sec.													

Station ID: Workstation 8

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T33	End of Line Inspection	14.00	1.00	14.00								
1	T34	Rolling Rod	195.00	1.00	195.00								
1	T32	Fuel Hose Fitment	281.00	1.00	281.00								
1	T35	Emission Analysis	44.00	1.00	44.00								
Total: 534.00 Sec.													

Station ID: Workstation 9

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T36	CO & Oil Temperature	139.00	1.00	139.00								
Total: 139.00 Sec.													

From the table above, it was seen that workstation 9 has 139seconds for doing the task assigned to it i.e. the station is idle for 437second. Reducing the takt time from 576seconds to 563.06seconds, the time – stations plot is shown in Figure 3 below.

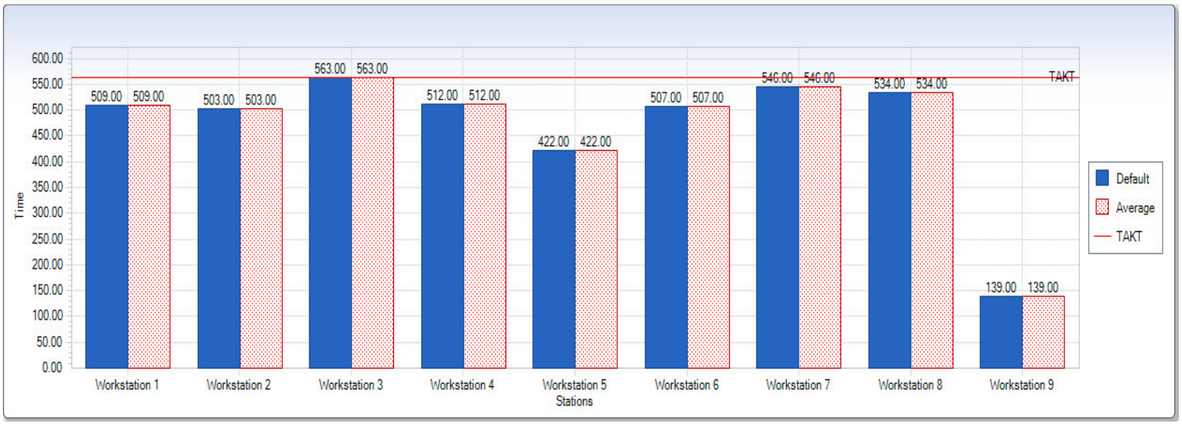

Figure 4: Time – Station plot for a cycle time of 563.06seconds

The station balance details is shown in the table below for a cycle time of 563.06seconds

Table 4: Station Balance details for a cycle time of 563.06seconds

Table 4. Station Balance Report grouping task into stations

Takt Time:	563.06 sec.				
Total Line Time:	4235 sec.				
	Maximum	Minimum		Average	
Station Time (Sec.)	563	139		470.56	
Idle Time (Sec.)	424.06	0.06		92.5	
Utilization (%)	100.00	25.00		84.00	
Workstation	Avg. Wt. Time (secs)	Avg. Time (secs)	Avg. Utilization (%)	No. of Operators	Avg. Idle Time (secs)
Workstation 1	509	509	90.00	1	54.06
Workstation 2	503	503	89.00	1	60.06
Workstation 3	563	563	100.00	1	0.06
Workstation 4	512	512	91.00	1	51.06
Workstation 5	422	422	75.00	1	141.06
Workstation 6	507	507	90.00	1	56.06
Workstation 7	546	546	97.00	1	17.06
Workstation 8	534	534	95.00	1	29.06
Workstation 9	139	139	25.00	1	424.06

From the table above, it was seen that the maximum station, minimum station and average station time remained the same i.e. 563seconds, 139seconds and 470.56seconds respectively. The maximum idle time, minimum idle time and average idle time reduced from 437seconds, 13seconds and 105.44seconds to 424seconds, 0.06seconds and 93.5seconds respectively. It was also seen that from the table above that the maximum utilization, minimum utilization and average utilization increased from 98%, 24% and 82% to 100%, 25% and 84% respectively. The details of the tasks in each workstation are shown in table 5 below.

Table 5. Task in each workstation for a cycle time of 563.06seconds

Takt Time: 563.06 Sec.

Total Line Time: 4235 Sec.

Station ID: Workstation 1

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T7	Chassis Preparation	218.00	1.00	218.00								
1	T8	Rear Suspension Fitment	109.00	1.00	109.00								
1	T9	Brake Hose Fitment	109.00	1.00	109.00								
1	T10	Shock Absorber	73.00	1.00	73.00								
Total: 509.00 Sec.													

Station ID: Workstation 2

									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T11	Hand Brake Cable Fitment	140.00	1.00	140.00								
1	T12	Hand Brake Drum Fitment	58.00	1.00	58.00								
1	T13	Repositioning of Chassis	139.00	1.00	139.00								
1	T14	Packaging Back Frame	166.00	1.00	166.00								
Total: 503.00 Sec.													

Station ID: Workstation 3

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T15	Head Lamp Fitment LHS	87.00	1.00	87.00								
1	T16	Head Lamp Fitment RHS	73.00	1.00	73.00								
1	T17	Front - Suspension -1	274.00	1.00	274.00								
1	T18	Front - Suspension -2	129.00	1.00	129.00								
Total: 563.00 Sec.													

Station ID: Workstation 4

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T19	Head Lamp Fitment - 3	123.00	1.00	123.00								
1	T20	Front Brake Hose Connection	65.00	1.00	65.00								
1	T21	Rear Tyre Fitment	301.00	1.00	301.00								
1	T22	Horn	23.00	1.00	23.00								
Total: 512.00 Sec.													

Station ID: Workstation 5

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T1	Engine Unpacking	32.00	1.00	32.00								
1	T2	Exhaust / Muffler Fitment	138.00	1.00	138.00								
1	T3	Drive Shaft Fitment	91.00	1.00	91.00								
1	T4	Air Box Fitment	62.00	1.00	62.00								
1	T5	Front Cross Member	61.00	1.00	61.00								
1	T6	Gear Oil	38.00	1.00	38.00								
Total: 422.00 Sec.													

Station ID: Workstation 6

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T23	Handle Bar	65.00	1.00	65.00								
1	T24	Brake Fluid Topping & Bleeding	113.00	1.00	113.00								
1	T25	Brake Fluid Topping &Bleeding	140.00	1.00	140.00								
1	T26	Brake Fluid Topping & Bleeding	141.00	1.00	141.00								
1	T27	Engine Chassis Feeding	48.00	1.00	48.00								
Total: 507.00 Sec.													

Station ID: Workstation 7

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T28	Rear Arm To Frame	111.00	1.00	111.00								
1	T29	Drive Shaft Fitment	124.00	1.00	124.00								
1	T30	Control Cable Fitment1	169.00	1.00	169.00								
1	T31	Control Cable Fitment 2	142.00	1.00	142.00								
Total: 546.00 Sec.													

Station ID: Workstation 8

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T32	Fuel Hose Fitment	281.00	1.00	281.00								
1	T33	End of Line Inspection	14.00	1.00	14.00								
1	T34	Rolling Rod	195.00	1.00	195.00								
1	T35	Emission Analysis	44.00	1.00	44.00								
Total: 534.00 Sec.													

Station ID: Workstation 9

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T36	CO & Oil Temperature	139.00	1.00	139.00								
Total: 139.00 Sec.													

From the foregoing, it was seen that reducing takt time and increasing the number of workstation increased the percent utilization and also reduced the total idle time and idle time across each workstation. For further analysis, the takt time was increased to 600seconds and the numbers of workstations was reduced to eight workstations. The time – station graph for one operator is shown in Figure 5 below.

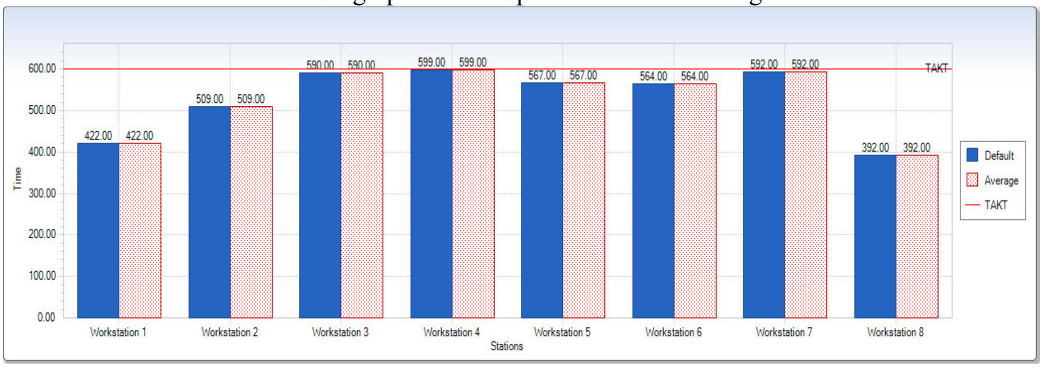

Figure 5: Time – Station Graph for a takt time of 600seconds

Table 6. Station Balance Report grouping task into stations

Takt Time:	600.00 sec.				
Total Line Time:	4235 sec.				
	Maximum	Minimum		Average	
Station Time (Sec.)	599	392		529.38	
Idle Time (Sec.)	208	1		70.62	
Utilization (%)	100.00	65.00		88.00	
Workstation	Avg. Wt. Time (secs)	Avg. Time (secs)	Avg. Utilization (%)	No. of Operators	Avg. Idle Time (secs)
Workstation 1	422	422	70.00	1	178.00
Workstation 2	509	509	85.00	1	91.00
Workstation 3	590	590	98.00	1	10.00
Workstation 4	599	599	100.00	1	1.00
Workstation 5	567	567	94.00	1	33.00
Workstation 6	564	564	94.00	1	36.00
Workstation 7	592	592	99.00	1	8.00
Workstation 8	392	392	65.00	1	208.00

The summary of the task in each of the eight workstations is given in the table 7 below.

Table 7. Task in each workstation for a takt time of 600seconds

Takt Time: 600 Sec.

Total Line Time: 4235 Sec.

Station ID: Workstation 1

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T1	Engine Unpacking	32.00	1.00	32.00								
1	T2	Exhaust / Muffler Fitment	138.00	1.00	138.00								
1	T3	Drive Shaft Fitment	91.00	1.00	91.00								
1	T4	Air Box Fitment	62.00	1.00	62.00								
1	T5	Front Cross Member	61.00	1.00	61.00								
1	T6	Gear Oil	38.00	1.00	38.00								
Total: 422.00 Sec.													

Station ID: Workstation 2

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T7	Chassis Preparation	218.00	1.00	218.00								
1	T8	Rear Suspension Fitment	109.00	1.00	109.00								
1	T9	Brake Hose Fitment	109.00	1.00	109.00								
1	T10	Shock Absorber	73.00	1.00	73.00								
Total: 509.00 Sec.													

Station ID: Workstation 3

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T11	Hand Brake Cable Fitment	140.00	1.00	140.00								
1	T12	Hand Brake Drum Fitment	58.00	1.00	58.00								
1	T13	Repositioning of Chassis	139.00	1.00	139.00								
1	T14	Packaging Back Frame	166.00	1.00	166.00								
1	T15	Head Lamp Fitment LHS	87.00	1.00	87.00								
Total: 590.00 Sec.													

Station ID: Workstation 4

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T18	Front - Suspension -2	129.00	1.00	129.00								
1	T16	Head Lamp Fitment RHS	73.00	1.00	73.00								
1	T17	Front - Suspension -1	274.00	1.00	274.00								
1	T19	Head Lamp Fitment - 3	123.00	1.00	123.00								
Total: 599.00 Sec.													

Station ID: Workstation 5

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T20	Front Brake Hose Connection	65.00	1.00	65.00								
1	T21	Rear Tyre Fitment	301.00	1.00	301.00								
1	T22	Horn	23.00	1.00	23.00								
1	T23	Handle Bar	65.00	1.00	65.00								
1	T24	Brake Fluid Topping & Bleeding	113.00	1.00	113.00								
Total: 567.00 Sec.													

Station ID: Workstation 6

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T27	Engine Chassis Feeding	48.00	1.00	48.00								
1	T26	Brake Fluid Topping & Bleeding	141.00	1.00	141.00								
1	T25	Brake Fluid Topping & Bleeding	140.00	1.00	140.00								
1	T28	Rear Arm To Frame	111.00	1.00	111.00								
1	T29	Drive Shaft Fitment	124.00	1.00	124.00								
Total: 564.00 Sec.													

Station ID: Workstation 7

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T30	Control Cable Fitment1	169.00	1.00	169.00								
1	T31	Control Cable Fitment 2	142.00	1.00	142.00								
1	T32	Fuel Hose Fitment	281.00	1.00	281.00								
Total: 592.00 Sec.													

Station ID: Workstation 8

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T35	Emission Analysis	44.00	1.00	44.00								
1	T36	CO & Oil Temperature	139.00	1.00	139.00								
1	T33	End of Line Inspection	14.00	1.00	14.00								
1	T34	Rolling Rod	195.00	1.00	195.00								
Total: 392.00 Sec.													

Increasing the takt time from 563.06seconds to 600seconds, it was seen from table 6 above, that the maximum station time, minimum station time and average station time was 599 seconds, 392seconds and 529.38seconds respectively. The maximum idle time is 208seconds which is smaller than 424seconds recorded when the takt time and workstation was 563.06 seconds and nine workstations respectively. A little improvement was made in the minimum idle time which was 1second compared to 0.06second. The average idle time reduced to 70.62 seconds compared to 92.5 seconds average idle time recorded when the takt time was 563.06 seconds in nine (9) workstations The maximum utilization recorded was 100% and this was the same as that recorded above, but minimum utilization increased from 25% to 65%. From the foregoing, there is an improvement in the value gotten for the minimum utilization time. The average utilization i.e. for the eight workstations was 88% which is higher than 84% average utilization record when the takt time was 563.06seconds in nine (9) workstations.

3.2 Multilayer Perceptron Neural Network Algorithm

The multilayer perception neural network algorithm was implemented in predicting the output (takt time) for the fifteen (15) days with the task or operation to be performed in the assembly of the tricycle as covariates in the input layer. The table 8 presents the Case Processing Summary of data used in training and testing the model.

Table 8. Case Processing Summary of Samples for the MLP Neural Network

		N	Percent
Sample	Training	11	73.3%
	Testing	4	26.7%
Valid		15	100.0%
Excluded		1	
Total		16	

The case processing summary showed that eleven (11) cases were assigned to the training sample and four (4) cases were assigned to the testing. One (1) case was excluded from the analysis and this represents the cycle time. The table 9 below shows the network information.

The network information table displayed information about the neural network and this was useful for ensuring that the specifications are correct. From the table, the number of units in the input layer was the number of covariates i.e. the thirty – six (36) tasks to be performed in the assembly of a tricycle. For the Online training using the gradient descent algorithm, the total number of hidden layer was ten (10). A separate unit was created for the output in the output layer.

Table 9. Model Summary

Training	Sum of Square Error	1.232
	Relative Error	.246
	Stopping Rule Used	1 consecutive step(s) with no decrease in error[a]
	Training Time	0:00:00.03
Testing	Sum of Squares Error	.260
	Relative Error	.572

Dependent Variable: Takt Time

a. Error computations are based on the testing sample.

The table above display the model summary information about the result of training and applying the final network to the testing sample. It was seen that the Sum of Square Error was 1.232. This was the error function that the network tries to minimize during training. The estimation algorithm stopped because the maximum number of epochs was reached. Ideally, the training stopped because the error converged. This raised questions about whether something went wrong during training and was something to keep in mind while further inspecting the output. The parameter estimates is shown in the table 7 above and it shows the Predictor and Predicted parameter for the MLP Neural Networks.

The stopping rule (1 consecutive step(s) with no decrease in errora) reported in the model summary table makes us suspect that the network may be under training. In checking that the network was not under training, the training and testing samples were recreated using correlations between the takt time and Predicted Value for Takt Time. Correlations measured how the variables or rank order are related using the Pearson's Correlation coefficient to measure the linear association and this is shown in the table below. The table above presents the MLP Predicted value for the takt time for the fifteen (15) days, with the maximum at 600.2seconds and minimum at 526.9seconds. The maximum and minimum Takt Time predicted using the Multilayer Perceptron Neural Network algorithm was used in checking the balance of the workstation in the assembly line with the maximum and minimum idle time, maximum and minimum utilization as balance criteria. For the maximum prediction of 600.2seconds, the time – station bar chart using the peak model balance algorithm is shown in the figure below.

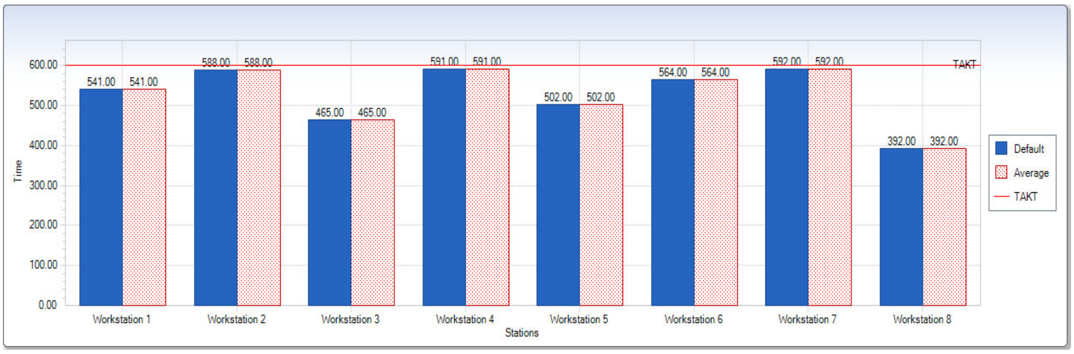

Figure 6: Time – Station Bar Chart for a Takt Time of 600.2seconds

Table 10. Station Balance Report grouping task into stations

Takt Time:	600.20 sec.				
Total Line Time:	4235 sec.				
	Maximum	Minimum		Average	
Station Time (Sec.)	592	392		529.38	
Idle Time (Sec.)	208.2	8.2		70.83	
Utilization (%)	99.00	65.00		88.00	
Workstation	Avg. Wt. Time (secs)	Avg. Time (secs)	Avg. Utilization (%)	No. of Operators	Avg. Idle Time (secs)
Workstation 1	541	541	90.00	1	59.20
Workstation 2	588	588	98.00	1	12.20
Workstation 3	465	465	77.00	1	135.20
Workstation 4	591	591	98.00	1	9.20
Workstation 5	502	502	84.00	1	98.20
Workstation 6	564	564	94.00	1	36.20
Workstation 7	592	592	99.00	1	8.20
Workstation 8	392	392	65.00	1	208.20

From the table above, it was seen that the total number of workstation for the various tasks performed in the tricycle assembly line was eight (8) for a takt time of 600.2seconds. The maximum, minimum and average station time was 592seconds, 392seconds and 529.38seconds respectively. The maximum idle time (208.2seconds) was appreciable as it was not up to half of the takt time, the minimum and average idle time – 8.2seconds and 70.83seconds respectively was relatively low and this is tolerable. The summary of the task in each of the eight (8) workstations is shown in the table below.

Table 11. Task in each workstation for a takt time of 600.2seconds

Takt Time: 600.2 Sec.

Total Line Time: 4235 Sec.

Station ID: Workstation 1

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T7	Chassis Preparation	218.00	1.00	218.00								
1	T8	Rear Suspension Fitment	109.00	1.00	109.00								
1	T1	Engine Unpacking	32.00	1.00	32.00								
1	T9	Brake Hose Fitment	109.00	1.00	109.00								
1	T10	Shock Absorber	73.00	1.00	73.00								
Total: 541.00 Sec.													

Station ID: Workstation 2

Processes								Required Resources			Required Parts	
1	T11	Hand Brake Cable Fitment	140.00	1.00	140.00							
1	T2	Exhaust / Muffler Fitment	138.00	1.00	138.00							
1	T3	Drive Shaft Fitment	91.00	1.00	91.00							
1	T4	Air Box Fitment	62.00	1.00	62.00							
1	T5	Front Cross Member	61.00	1.00	61.00							
1	T6	Gear Oil	38.00	1.00	38.00							
1	T12	Hand Brake Drum Fitment	58.00	1.00	58.00							
Total: 588.00 Sec.												

Station ID: Workstation 3

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T13	Repositioning of Chassis	139.00	1.00	139.00								
1	T14	Packaging Back Frame	166.00	1.00	166.00								
1	T15	Head Lamp Fitment LHS	87.00	1.00	87.00								
1	T16	Head Lamp Fitment RHS	73.00	1.00	73.00								
Total: 465.00 Sec.													

Station ID: Workstation 4

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T17	Front - Suspension -1	274.00	1.00	274.00								
1	T18	Front - Suspension -2	129.00	1.00	129.00								
1	T19	Head Lamp Fitment -3	123.00	1.00	123.00								
1	T20	Front Brake Hose Connection	65.00	1.00	65.00								
Total: 591.00 Sec.													

Station ID: Workstation 5

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T21	Rear Tyre Fitment	301.00	1.00	301.00								
1	T22	Horn	23.00	1.00	23.00								
1	T23	Handle Bar	65.00	1.00	65.00								
1	T24	Brake Fluid Topping & Bleeding	113.00	1.00	113.00								
Total: 502.00 Sec.													

Station ID: Workstation 6

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T25	Brake Fluid Topping & Bleeding	140.00	1.00	140.00								
1	T26	Brake Fluid Topping & Bleeding	141.00	1.00	141.00								
1	T27	Engine Chassis Feeding	48.00	1.00	48.00								
1	T28	Rear Arm To Frame	111.00	1.00	111.00								
	T29	Drive Shaft Fitment	124.00	1.00	124.00								
Total: 564.00 Sec.													

Station ID: Workstation 7

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T30	Control Cable Fitment1	169.00	1.00	169.00								
1	T31	Control Cable Fitment 2	142.00	1.00	142.00								
1	T32	Fuel Hose Fitment	281.00	1.00	281.00								
Total: 592.00 Sec.													

Station ID: Workstation 8

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T33	End of Line Inspection	14.00	1.00	14.00								
1	T34	Rolling Rod	195.00	1.00	195.00								
1	T35	Emission Analysis	44.00	1.00	44.00								
1	T36	CO & Oil Temperature	139.00	1.00	139.00								
Total: 392.00 Sec.													

For the minimum (lowest) value of MLP_PredictedValue i.e. 526.9seconds the time – station bar chart using the peak model balance algorithm and the station balance table is shown below.

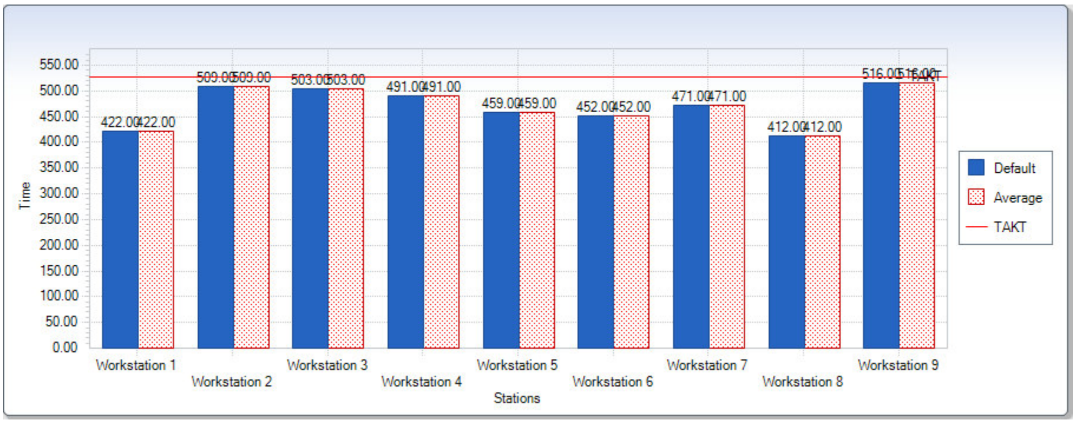

Figure 7: Time – Station Bar Chart for a Takt Time of 526.9seconds

Table 12. Station Balance Details for a takt time of 526.9seconds

Takt Time:	526.90 sec.				
Total Line Time:	4235 sec.				
	Maximum	Minimum		Average	
Station Time (Sec.)	516	412		470.56	
Idle Time (Sec.)	114.90	10.9		56.34	
Utilization (%)	98.00	78.00		89.00	
Workstation	Avg. Wt. Time (secs)	Avg. Time (secs)	Avg. Utilization (%)	No. of Operators	Avg. Idle Time (secs)
Workstation 1	422	422	80.00	1	104.90
Workstation 2	509	509	97.00	1	17.90
Workstation 3	503	503	95.00	1	23.90
Workstation 4	491	491	93.00	1	35.90
Workstation 5	459	459	87.00	1	67.90
Workstation 6	452	452	86.00	1	74.90
Workstation 7	471	471	89.00	1	55.90
Workstation 8	412	412	78.00	1	114.90
Workstation 9	516	516	98.00	1	10.90

Table 13. Task in Each Workstation for a takt time of 526.9seconds

Takt Time:526.9 Sec.

Total Line Time: 4235 Sec.

Station ID: Workstation 1

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T1	Engine Unpacking	32.00	1.00	32.00								
1	T2	Exhaust / Muffler Fitment	138.00	1.00	138.00								
1	T3	Drive Shaft Fitment	91.00	1.00	91.00								
1	T4	Air Box Fitment	62.00	1.00	62.00								
1	T5	Front Cross Member	61.00	1.00	61.00								
1	T6	Gear Oil	38.00	1.00	38.00								
Total: 422.00 Sec.													

Station ID: Workstation 2

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T7	Chassis Preparation	218.00	1.00	218.00								
1	T8	Rear Suspension Fitment	109.00	1.00	109.00								
1	T9	Brake Hose Fitment	109.00	1.00	109.00								
1	T10	Shock Absorber	73.00	1.00	73.00								
Total: 509.00 Sec.													

Station ID: Workstation 3

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T11	Hand Brake Cable Fitment	140.00	1.00	140.00								
1	T12	Hand Brake Drum Fitment	58.00	1.00	58.00								
1	T13	Repositioning of Chassis	139.00	1.00	139.00								
1	T14	Packaging Back Frame	166.00	1.00	166.00								
Total: 503.00 Sec.													

Station ID: Workstation 4

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T15	Front - Suspension -1	274.00	1.00	274.00								
1	T16	Front - Suspension -2	129.00	1.00	129.00								
1	T17	Front Brake Hose Connection	65.00	1.00	65.00								
1	T18	Horn	23.00	1.00	23.00								
Total: 491.00 Sec.													

Station ID: Workstation 5

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T19	Handle Bar	65.00	1.00	65.00								
1	T20	Brake Fluid Topping & Bleeding	113.00	1.00	113.00								
1	T21	Brake Fluid Topping & Bleeding	140.00	1.00	140.00								
1	T22	Brake Fluid Topping & Bleeding	141.00	1.00	141.00								
Total: 459.00 Sec.													

Station ID: Workstation 6

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T23	Head Lamp Fitment LHS	87.00	1.00	87.00								
1	T24	Head Lamp Fitment RHS	73.00	1.00	73.00								
1	T25	Head Lamp Fitment - 3	123.00	1.00	123.00								
1	T26	Control Cable Fitment1	169.00	1.00	169.00								
Total: 452.00 Sec.													

Station ID: Workstation 7

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
	T27	Engine Chassis Feeding	48.00	1.00	48.00								
1	T28	Control Cable Fitment 2	142.00	1.00	142.00								
1	T29	Fuel Hose Fitment	281.00	1.00	281.00								
Total: 471.00 Sec.													

Station ID: Workstation 8

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T30	Rear Tyre Fitment	301.00	1.00	301.00								
1	T31	Rear Arm To Frame	111.00	1.00	111.00								
Total: 412.00 Sec.													

Station ID: Workstation 9

Processes									Required Resources			Required Parts	
Oper.	ID	Description	Net Time (Sec.)	Take Rate	Wt. Time (Sec.)	Work Zones	Models	Options	ID	Description	Qty.	ID	Description
1	T32	Drive Shaft Fitment	124.00	1.00	124.00								
1	T33	End of Line Inspection	14.00	1.00	14.00								
1	T34	Rolling Rod	195.00	1.00	195.00								
1	T35	Emission Analysis	44.00	1.00	44.00								
1	T36	CO & Oil Temperature	139.00	1.00	139.00								
Total: 516.00 Sec.													

From table 12, it is seen that the maximum, minimum and average station time was 516secs, 412secs and 470.56secs respectively. The maximum, minimum and average idle time was 144.9secs, 10.9secs and 56.34secs which was more appreciable than the values gotten when the takt time was 600.2secs. This was fair enough to avoid bottlenecks. It was seen that there was improvement in the maximum, minimum and average utilization i.e. 98%, 78% and 89% respectively. The maximum utilization was appreciable as an efficiency of 100% is not possible.

4. Conclusion

In comparing the standard cycle time of 576secs in Boulous Enterprises Limited and the predicted cycle time using artificial neural network, it was discovered that the standard cycle time of 576secs in eight (8) workstations resulted in a maximum, minimum and average utilization values of 236%, 5%and 91.9% respectively. While the maximum, minimum and average idle time values were 547secs, 0.00secs and 105.44secs respectively, this is not feasible. After testing and training using artificial neural network, it was observed that the maximum value of cycle time was 600.2secs and the minimum was 526.9secs. The multilayer perceptron neural network algorithm was implemented using the online type of training and the gradient descent optimization algorithm. The minimum and maximum number of units was 1 and 10 respectively. The minimum value of the cycle time predicted by the multilayer perceptron neural network algorithm was 526.9secs, for nine (9) workstations. When analyzed, this gave maximum, minimum and average utilization values of 98%, 78% and 89% respectively. This resulted in the reduction of the maximum station idle time to 148.9secs and minimized bottlenecks as the minimum station idle time was 12secs and an average of 56.34secs. In summary, the existing line layout in Boulous was greatly improved upon, as the results obtained from the Artificial Neural Network training showed that the output per day was increased from 50 to 55. Also, the cycle time was reduced from 576.0secs to 526.9secs and the average idle time from 105.4secs to 56.3secs which is a pardonable time.

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