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

A. I. UNUIGBE1*, H.A. UNUIGBE2, B. EHEBHAMEN3, C. EKHAREAFO4
1. Department of Industrial and Production Engineering, Ambrose Alli University, Ekpoma, NIGERIA, 2. Lloyd’s Register EMEA (Nigeria) Ltd. Gte. 6th Floor, B Wing, Shippers Plaza, 4, Park Lane, Apapa, Lagos,

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 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.

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.

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

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

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

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

2.4 Theoretical number of workstations
Mathematically,

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

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

\[
\text{Efficiency} = \frac{\text{Sum of Task Times}}{\text{Cycle Time x Number of Actual Workstations}} \times 100\% \quad [3]
\]

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.
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

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

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 perceptron 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 576 seconds (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 576 seconds

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

Table 2. Station Balance Report grouping task into stations

<table>
<thead>
<tr>
<th>Takt Time:</th>
<th>576 sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Line Time:</td>
<td>4235 sec.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum</th>
<th>Minimum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station Time (Sec.)</td>
<td>563</td>
<td>139</td>
</tr>
<tr>
<td>Idle Time (Sec.)</td>
<td>437</td>
<td>13</td>
</tr>
<tr>
<td>Utilization (%)</td>
<td>98.00</td>
<td>24.00</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Workstation 1</td>
<td>422</td>
<td>422</td>
<td>73</td>
<td>1</td>
<td>154</td>
</tr>
<tr>
<td>Workstation 2</td>
<td>509</td>
<td>509</td>
<td>88</td>
<td>1</td>
<td>67</td>
</tr>
<tr>
<td>Workstation 3</td>
<td>503</td>
<td>503</td>
<td>87</td>
<td>1</td>
<td>73</td>
</tr>
<tr>
<td>Workstation 4</td>
<td>563</td>
<td>563</td>
<td>98</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Workstation 5</td>
<td>512</td>
<td>512</td>
<td>89</td>
<td>1</td>
<td>89</td>
</tr>
<tr>
<td>Workstation 6</td>
<td>507</td>
<td>507</td>
<td>88</td>
<td>1</td>
<td>69</td>
</tr>
<tr>
<td>Workstation 7</td>
<td>546</td>
<td>546</td>
<td>95</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>Workstation 8</td>
<td>534</td>
<td>534</td>
<td>93</td>
<td>1</td>
<td>42</td>
</tr>
<tr>
<td>Workstation 9</td>
<td>139</td>
<td>139</td>
<td>24</td>
<td>1</td>
<td>437</td>
</tr>
</tbody>
</table>

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. 563 seconds with an idle time of 13 seconds, while workstation 9 has the minimum station time of 139 seconds and idle time of 437 seconds. For the nine workstations, the average station time was 470.56 seconds, an average idle time of 105.44 seconds 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
<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty.</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Engine Unpacking</td>
<td>32.00</td>
<td>1.00</td>
<td>32.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td>Exhaust / Muffler Fitment</td>
<td>138.00</td>
<td>1.00</td>
<td>138.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3</td>
<td>Drive Shaft Fitment</td>
<td>91.00</td>
<td>1.00</td>
<td>91.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T4</td>
<td>Air Box Fitment</td>
<td>62.00</td>
<td>1.00</td>
<td>62.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T5</td>
<td>Front Cross Member</td>
<td>61.00</td>
<td>1.00</td>
<td>61.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T6</td>
<td>Gear Oil</td>
<td>38.00</td>
<td>1.00</td>
<td>38.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>422.00 Sec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Station ID: Workstation 2

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Work Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T7 Chassis Preparation</td>
<td>218.00</td>
<td>1.00</td>
<td>218.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T8 Rear Suspension Fitment</td>
<td>109.00</td>
<td>1.00</td>
<td>109.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T9 Brake Hose Fitment</td>
<td>109.00</td>
<td>1.00</td>
<td>109.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T10 Shock Absorber</td>
<td>73.00</td>
<td>1.00</td>
<td>73.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong>: 509.00 Sec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Station ID: Workstation 3

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Work Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T11 Hand Brake Cable Fitment</td>
<td>140.00</td>
<td>1.00</td>
<td>140.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T12 Hand Brake Drum Fitment</td>
<td>58.00</td>
<td>1.00</td>
<td>58.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T13 Repositioning of Chassis</td>
<td>139.00</td>
<td>1.00</td>
<td>139.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T14 Packaging Back Frame</td>
<td>166.00</td>
<td>1.00</td>
<td>166.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong>: 503.00 Sec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Station ID: Workstation 4

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Work Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T15 Head Lamp Fitment LHS</td>
<td>87.00</td>
<td>1.00</td>
<td>87.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T16 Head Lamp Fitment RHS</td>
<td>73.00</td>
<td>1.00</td>
<td>73.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T17 Front - Suspension -1</td>
<td>274.00</td>
<td>1.00</td>
<td>274.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T18 Front - Suspension -2</td>
<td>129.00</td>
<td>1.00</td>
<td>129.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong>: 563.00 Sec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Station ID: Workstation 5

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Work Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T19 Head Lamp Fitment -3</td>
<td>123.00</td>
<td>1.00</td>
<td>123.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T20 Front Brake Hose Connection</td>
<td>65.00</td>
<td>1.00</td>
<td>65.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T21 Rear Tyre Fitment</td>
<td>301.00</td>
<td>1.00</td>
<td>301.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T22 Horn</td>
<td>23.00</td>
<td>1.00</td>
<td>23.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong>: 512.00 Sec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Station ID: Workstation 6

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID Description</th>
<th>Qty.</th>
<th>ID Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T27 Engine Chassis Feeding</td>
<td>48.00</td>
<td>1.00</td>
<td>48.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T23 Handle Bar</td>
<td>65.00</td>
<td>1.00</td>
<td>65.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T24 Brake Fluid Topping &amp; Bleeding</td>
<td>113.00</td>
<td>1.00</td>
<td>113.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T25 Brake Fluid Topping &amp; Bleeding</td>
<td>140.00</td>
<td>1.00</td>
<td>140.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T26 Brake Fluid Topping &amp; Bleeding</td>
<td>141.00</td>
<td>1.00</td>
<td>141.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td>507.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Station ID: Workstation 7

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID Description</th>
<th>Qty.</th>
<th>ID Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T30 Control Fitment 1</td>
<td>169.00</td>
<td>1.00</td>
<td>169.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T31 Control Fitment 2</td>
<td>142.00</td>
<td>1.00</td>
<td>142.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T28 Rear Arm To Frame</td>
<td>111.00</td>
<td>1.00</td>
<td>111.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T29 Drive Shaft Fitment</td>
<td>124.00</td>
<td>1.00</td>
<td>124.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td>546.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Station ID: Workstation 8

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID Description</th>
<th>Qty.</th>
<th>ID Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T33 End of Line Inspection</td>
<td>14.00</td>
<td>1.00</td>
<td>14.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T34 Rolling Rod</td>
<td>195.00</td>
<td>1.00</td>
<td>195.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T32 Fuel Hose Fitment</td>
<td>281.00</td>
<td>1.00</td>
<td>281.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T35 Emission Analysis</td>
<td>44.00</td>
<td>1.00</td>
<td>44.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td>534.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Station ID: Workstation 9

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID Description</th>
<th>Qty.</th>
<th>ID Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T36 CO &amp; Oil Temperature</td>
<td>139.00</td>
<td>1.00</td>
<td>139.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td>139.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From the table above, it was seen that workstation 9 has 139 seconds for doing the task assigned to it i.e. the station is idle for 437 seconds. Reducing the takt time from 576 seconds to 563.06 seconds, 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

| 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 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

| 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

<table>
<thead>
<tr>
<th>Oper.</th>
<th>ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty.</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T11</td>
<td>Hand Brake Cable Fitment</td>
<td>140.00</td>
<td>1.00</td>
<td>140.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T12</td>
<td>Hand Brake Drum Fitment</td>
<td>58.00</td>
<td>1.00</td>
<td>58.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T13</td>
<td>Repositioning of Chassis</td>
<td>139.00</td>
<td>1.00</td>
<td>139.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T14</td>
<td>Packaging Back Frame</td>
<td>166.00</td>
<td>1.00</td>
<td>166.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total: 503.00 Sec.

### Station ID: Workstation 3

<table>
<thead>
<tr>
<th>Oper.</th>
<th>ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty.</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T15</td>
<td>Head Lamp Fitment LHS</td>
<td>87.00</td>
<td>1.00</td>
<td>87.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T16</td>
<td>Head Lamp Fitment RHS</td>
<td>73.00</td>
<td>1.00</td>
<td>73.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T17</td>
<td>Front Suspension -1</td>
<td>- 274.00</td>
<td>1.00</td>
<td>274.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T18</td>
<td>Front Suspension -2</td>
<td>- 129.00</td>
<td>1.00</td>
<td>129.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total: 563.00 Sec.

### Station ID: Workstation 4

<table>
<thead>
<tr>
<th>Oper.</th>
<th>ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty.</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T19</td>
<td>Head Lamp Fitment - 3</td>
<td>123.00</td>
<td>1.00</td>
<td>123.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T20</td>
<td>Front Brake Hose Connection</td>
<td>65.00</td>
<td>1.00</td>
<td>65.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T21</td>
<td>Rear Tyre Fitment</td>
<td>301.00</td>
<td>1.00</td>
<td>301.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T22</td>
<td>Horn</td>
<td>23.00</td>
<td>1.00</td>
<td>23.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total: 512.00 Sec.
Station ID: Workstation 5

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 T1</td>
<td>Engine Unpacking</td>
<td>32.00</td>
<td>1.00</td>
<td>32.00</td>
</tr>
<tr>
<td>1 T2</td>
<td>Exhaust / Muffler Fitment</td>
<td>138.00</td>
<td>1.00</td>
<td>138.00</td>
</tr>
<tr>
<td>1 T3</td>
<td>Drive Shaft Fitment</td>
<td>91.00</td>
<td>1.00</td>
<td>91.00</td>
</tr>
<tr>
<td>1 T4</td>
<td>Air Box Fitment</td>
<td>62.00</td>
<td>1.00</td>
<td>62.00</td>
</tr>
<tr>
<td>1 T5</td>
<td>Front Cross Member</td>
<td>61.00</td>
<td>1.00</td>
<td>61.00</td>
</tr>
<tr>
<td>1 T6</td>
<td>Gear Oil</td>
<td>38.00</td>
<td>1.00</td>
<td>38.00</td>
</tr>
</tbody>
</table>

Total: 422.00 Sec.

Station ID: Workstation 6

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 T23</td>
<td>Handle Bar</td>
<td>65.00</td>
<td>1.00</td>
<td>65.00</td>
</tr>
<tr>
<td>1 T24</td>
<td>Brake Fluid Topping &amp; Bleeding</td>
<td>113.00</td>
<td>1.00</td>
<td>113.00</td>
</tr>
<tr>
<td>1 T25</td>
<td>Brake Fluid Topping &amp; Bleeding</td>
<td>140.00</td>
<td>1.00</td>
<td>140.00</td>
</tr>
<tr>
<td>1 T26</td>
<td>Brake Fluid Topping &amp; Bleeding</td>
<td>141.00</td>
<td>1.00</td>
<td>141.00</td>
</tr>
<tr>
<td>1 T27</td>
<td>Engine Chassis Feeding</td>
<td>48.00</td>
<td>1.00</td>
<td>48.00</td>
</tr>
</tbody>
</table>

Total: 507.00 Sec.

Station ID: Workstation 7

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 T28</td>
<td>Rear Arm To Frame</td>
<td>111.00</td>
<td>1.00</td>
<td>111.00</td>
</tr>
<tr>
<td>1 T29</td>
<td>Drive Shaft Fitment</td>
<td>124.00</td>
<td>1.00</td>
<td>124.00</td>
</tr>
<tr>
<td>1 T30</td>
<td>Control Cable Fitment1</td>
<td>169.00</td>
<td>1.00</td>
<td>169.00</td>
</tr>
<tr>
<td>1 T31</td>
<td>Control Cable Fitment 2</td>
<td>142.00</td>
<td>1.00</td>
<td>142.00</td>
</tr>
</tbody>
</table>

Total: 546.00 Sec.

Station ID: Workstation 8

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 T32</td>
<td>Fuel Hose Fitment</td>
<td>281.00</td>
<td>1.00</td>
<td>281.00</td>
</tr>
<tr>
<td>1 T33</td>
<td>End of Line Inspection</td>
<td>14.00</td>
<td>1.00</td>
<td>14.00</td>
</tr>
<tr>
<td>1 T34</td>
<td>Rolling Rod</td>
<td>195.00</td>
<td>1.00</td>
<td>195.00</td>
</tr>
<tr>
<td>1 T35</td>
<td>Emission Analysis</td>
<td>44.00</td>
<td>1.00</td>
<td>44.00</td>
</tr>
</tbody>
</table>

Total: 534.00 Sec.
Station ID: Workstation 9

<table>
<thead>
<tr>
<th>Processes</th>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T36</td>
<td>CO &amp; Oil Temperature</td>
<td>139.00</td>
<td>1.00</td>
<td>139.00</td>
</tr>
</tbody>
</table>

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 600 seconds 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 600 seconds

Table 6. Station Balance Report grouping task into stations

<table>
<thead>
<tr>
<th>Takt Time: 600.00 sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Line Time: 4235 sec.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Station Time (Sec.)</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idle Time (Sec.)</td>
<td>208</td>
<td>1</td>
<td>70.62</td>
</tr>
<tr>
<td>Utilization (%)</td>
<td>100.00</td>
<td>65.00</td>
<td>88.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Workstation 1</td>
<td>422</td>
<td>422</td>
<td>70.00</td>
<td>1</td>
<td>178.00</td>
</tr>
<tr>
<td>Workstation 2</td>
<td>509</td>
<td>509</td>
<td>85.00</td>
<td>1</td>
<td>91.00</td>
</tr>
<tr>
<td>Workstation 3</td>
<td>590</td>
<td>590</td>
<td>98.00</td>
<td>1</td>
<td>10.00</td>
</tr>
<tr>
<td>Workstation 4</td>
<td>599</td>
<td>599</td>
<td>100.00</td>
<td>1</td>
<td>1.00</td>
</tr>
<tr>
<td>Workstation 5</td>
<td>567</td>
<td>567</td>
<td>94.00</td>
<td>1</td>
<td>33.00</td>
</tr>
<tr>
<td>Workstation 6</td>
<td>564</td>
<td>564</td>
<td>94.00</td>
<td>1</td>
<td>36.00</td>
</tr>
<tr>
<td>Workstation 7</td>
<td>592</td>
<td>592</td>
<td>99.00</td>
<td>1</td>
<td>8.00</td>
</tr>
<tr>
<td>Workstation 8</td>
<td>392</td>
<td>392</td>
<td>65.00</td>
<td>1</td>
<td>208.00</td>
</tr>
</tbody>
</table>

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 600 seconds

**Takt Time:** 600 Sec.
**Total Line Time:** 4235 Sec.

#### Station ID: Workstation 1

<table>
<thead>
<tr>
<th>Processes</th>
<th>Required Resources</th>
<th>Required Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oper. ID</td>
<td>Description</td>
<td>Net Time (Sec.)</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>1</td>
<td>T1</td>
<td>Engine Unpacking</td>
</tr>
<tr>
<td>1</td>
<td>T2</td>
<td>Exhaust / Muffler Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T3</td>
<td>Drive Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T4</td>
<td>Air Box Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T5</td>
<td>Front Member Cross</td>
</tr>
<tr>
<td>1</td>
<td>T6</td>
<td>Gear Oil</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Station ID: Workstation 2

<table>
<thead>
<tr>
<th>Processes</th>
<th>Required Resources</th>
<th>Required Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oper. ID</td>
<td>Description</td>
<td>Net Time (Sec.)</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>1</td>
<td>T7</td>
<td>Chassis Preparation</td>
</tr>
<tr>
<td>1</td>
<td>T8</td>
<td>Rear Suspension Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T9</td>
<td>Brake Hose Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T10</td>
<td>Shock Absorber</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Station ID: Workstation 3

<table>
<thead>
<tr>
<th>Processes</th>
<th>Required Resources</th>
<th>Required Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oper. ID</td>
<td>Description</td>
<td>Net Time (Sec.)</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>1</td>
<td>T11</td>
<td>Hand Brake Cable Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T12</td>
<td>Hand Brake Drum Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T13</td>
<td>Repositioning of Chassis</td>
</tr>
<tr>
<td>1</td>
<td>T14</td>
<td>Packaging Back Frame</td>
</tr>
<tr>
<td>1</td>
<td>T15</td>
<td>Head Lamp Fitment LHS</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Station ID: Workstation 4

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty.</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T18 Front - Suspension -2</td>
<td>129.00</td>
<td>1.00</td>
<td>129.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T16 Head Lamp Fitment RHS</td>
<td>73.00</td>
<td>1.00</td>
<td>73.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T17 Front - Suspension -1</td>
<td>274.00</td>
<td>1.00</td>
<td>274.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T19 Head Lamp Fitment - 3</td>
<td>123.00</td>
<td>1.00</td>
<td>123.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td>599.00 Sec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Station ID: Workstation 5

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty.</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T20 Front Brake Hose Connection</td>
<td>65.00</td>
<td>1.00</td>
<td>65.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T21 Rear Tyre Fitment</td>
<td>301.00</td>
<td>1.00</td>
<td>301.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T22 Horn</td>
<td>23.00</td>
<td>1.00</td>
<td>23.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T23 Handle Bar</td>
<td>65.00</td>
<td>1.00</td>
<td>65.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T24 Brake Fluid Topping &amp; Bleeding</td>
<td>113.00</td>
<td>1.00</td>
<td>113.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td>567.00 Sec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Station ID: Workstation 6

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty.</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T27 Engine Chassis Feeding</td>
<td>48.00</td>
<td>1.00</td>
<td>48.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T26 Brake Fluid Topping &amp; Bleeding</td>
<td>141.00</td>
<td>1.00</td>
<td>141.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T25 Brake Fluid Topping &amp; Bleeding</td>
<td>140.00</td>
<td>1.00</td>
<td>140.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T28 Rear Arm To Frame</td>
<td>111.00</td>
<td>1.00</td>
<td>111.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T29 Drive Shaft Fitment</td>
<td>124.00</td>
<td>1.00</td>
<td>124.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td>564.00 Sec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Station ID: Workstation 7

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty.</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T30 Control Fitment1</td>
<td>169.00</td>
<td>1.00</td>
<td>169.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T31 Control Fitment 2</td>
<td>142.00</td>
<td>1.00</td>
<td>142.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T32 Fuel Hose Fitment</td>
<td>281.00</td>
<td>1.00</td>
<td>281.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td>592.00 Sec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Station ID: Workstation 8

<table>
<thead>
<tr>
<th>Processes</th>
<th>Required Resources</th>
<th>Required Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oper. ID</td>
<td>Description</td>
<td>Wt. (Sec.)</td>
</tr>
<tr>
<td>1</td>
<td>T35 Emission Analysis</td>
<td>44.00</td>
</tr>
<tr>
<td>1</td>
<td>T36 CO &amp; Temperature Oil</td>
<td>139.00</td>
</tr>
<tr>
<td>1</td>
<td>T33 End of Line Inspection</td>
<td>14.00</td>
</tr>
<tr>
<td>1</td>
<td>T34 Rolling Rod</td>
<td>195.00</td>
</tr>
</tbody>
</table>

Total: 392.00 Sec.

Increasing the takt time from 563.06 seconds to 600 seconds, it was seen from table 6 above, that the maximum station time, minimum station time and average station time was 599 seconds, 392 seconds and 529.38 seconds respectively. The maximum idle time is 208 seconds which is smaller than 424 seconds 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 1 second compared to 0.06 second. 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 563.06 seconds 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

<table>
<thead>
<tr>
<th>N</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Training</td>
<td>11</td>
</tr>
<tr>
<td>Testing</td>
<td>4</td>
</tr>
<tr>
<td>Valid</td>
<td>15</td>
</tr>
<tr>
<td>Excluded</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Training</th>
<th>Sum of Square Error</th>
<th>1.232</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Error</td>
<td>.246</td>
<td></td>
</tr>
<tr>
<td>Stopping Rule Used</td>
<td>1 consecutive step(s) with no decrease in error</td>
<td></td>
</tr>
<tr>
<td>Training Time</td>
<td></td>
<td>0:00:00.03</td>
</tr>
<tr>
<td>Testing</td>
<td>Sum of Squares Error</td>
<td>.260</td>
</tr>
<tr>
<td>Relative Error</td>
<td>.572</td>
<td></td>
</tr>
</tbody>
</table>

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](image)

**Table 10. Station Balance Report grouping task into stations**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Station Time (Sec.)</td>
<td>Maximum</td>
<td>Minimum</td>
<td>Average</td>
</tr>
<tr>
<td>Idle Time (Sec.)</td>
<td>208.2</td>
<td>8.2</td>
<td>70.83</td>
</tr>
<tr>
<td>Utilization (%)</td>
<td>99.00</td>
<td>65.00</td>
<td>88.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Workstation 1</td>
<td>541</td>
<td>541</td>
<td>90.00</td>
<td>1</td>
<td>59.20</td>
</tr>
<tr>
<td>Workstation 2</td>
<td>588</td>
<td>588</td>
<td>98.00</td>
<td>1</td>
<td>12.20</td>
</tr>
<tr>
<td>Workstation 3</td>
<td>465</td>
<td>465</td>
<td>77.00</td>
<td>1</td>
<td>135.20</td>
</tr>
<tr>
<td>Workstation 4</td>
<td>591</td>
<td>591</td>
<td>98.00</td>
<td>1</td>
<td>9.20</td>
</tr>
<tr>
<td>Workstation 5</td>
<td>502</td>
<td>502</td>
<td>84.00</td>
<td>1</td>
<td>98.20</td>
</tr>
<tr>
<td>Workstation 6</td>
<td>564</td>
<td>564</td>
<td>94.00</td>
<td>1</td>
<td>36.20</td>
</tr>
<tr>
<td>Workstation 7</td>
<td>592</td>
<td>592</td>
<td>99.00</td>
<td>1</td>
<td>8.20</td>
</tr>
<tr>
<td>Workstation 8</td>
<td>392</td>
<td>392</td>
<td>65.00</td>
<td>1</td>
<td>208.20</td>
</tr>
</tbody>
</table>

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 600.2 seconds

<table>
<thead>
<tr>
<th>Processes</th>
<th>Required Resources</th>
<th>Required Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oper. ID</td>
<td>Description</td>
<td>Net Time (Sec.)</td>
</tr>
<tr>
<td>1</td>
<td>T7</td>
<td>Chassis Preparation</td>
</tr>
<tr>
<td>1</td>
<td>T8</td>
<td>Rear Suspension Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T1</td>
<td>Engine Unpacking</td>
</tr>
<tr>
<td>1</td>
<td>T9</td>
<td>Brake Hose Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T10</td>
<td>Shock Absorber</td>
</tr>
<tr>
<td>Total:</td>
<td>541.00 Sec.</td>
<td></td>
</tr>
</tbody>
</table>

Station ID: Workstation 2

<table>
<thead>
<tr>
<th>Processes</th>
<th>Required Resources</th>
<th>Required Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oper. ID</td>
<td>Description</td>
<td>Net Time (Sec.)</td>
</tr>
<tr>
<td>1</td>
<td>T11</td>
<td>Hand Brake Cable Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T2</td>
<td>Exhaust / Muffler Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T3</td>
<td>Drive Shaft Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T4</td>
<td>Air Box Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T5</td>
<td>Front Cross Member</td>
</tr>
<tr>
<td>1</td>
<td>T6</td>
<td>Gear Oil</td>
</tr>
<tr>
<td>1</td>
<td>T12</td>
<td>Hand Brake Drum Fitment</td>
</tr>
<tr>
<td>Total:</td>
<td>588.00 Sec.</td>
<td></td>
</tr>
</tbody>
</table>

Station ID: Workstation 3

<table>
<thead>
<tr>
<th>Processes</th>
<th>Required Resources</th>
<th>Required Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oper. ID</td>
<td>Description</td>
<td>Net Time (Sec.)</td>
</tr>
<tr>
<td>1</td>
<td>T13</td>
<td>Repositioning Chassis</td>
</tr>
<tr>
<td>1</td>
<td>T14</td>
<td>Packaging Back Frame</td>
</tr>
<tr>
<td>1</td>
<td>T15</td>
<td>Head Lamp LHS Fitment</td>
</tr>
<tr>
<td>1</td>
<td>T16</td>
<td>Head Lamp RHS Fitment</td>
</tr>
<tr>
<td>Total:</td>
<td>465.00 Sec.</td>
<td></td>
</tr>
</tbody>
</table>
### Station ID: Workstation 4

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models Options</th>
<th>ID Description</th>
<th>Qty</th>
<th>ID Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T17 Front - Suspension -1</td>
<td>274.00</td>
<td>1.00</td>
<td>274.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T18 Front - Suspension -2</td>
<td>129.00</td>
<td>1.00</td>
<td>129.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T19 Head Lamp Fitment -3</td>
<td>123.00</td>
<td>1.00</td>
<td>123.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T20 Front Brake Hose Connection</td>
<td>65.00</td>
<td>1.00</td>
<td>65.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total: 591.00 Sec.

### Station ID: Workstation 5

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models Options</th>
<th>ID Description</th>
<th>Qty</th>
<th>ID Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T21 Rear Tyre Fitment</td>
<td>301.00</td>
<td>1.00</td>
<td>301.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T22 Horn</td>
<td>23.00</td>
<td>1.00</td>
<td>23.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T23 Handle Bar</td>
<td>65.00</td>
<td>1.00</td>
<td>65.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T24 Brake Fluid Topping &amp; Bleeding</td>
<td>113.00</td>
<td>1.00</td>
<td>113.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total: 502.00 Sec.

### Station ID: Workstation 6

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models Options</th>
<th>ID Description</th>
<th>Qty</th>
<th>ID Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T25 Brake Fluid Topping &amp; Bleeding</td>
<td>140.00</td>
<td>1.00</td>
<td>140.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T26 Brake Fluid Topping &amp; Bleeding</td>
<td>141.00</td>
<td>1.00</td>
<td>141.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T27 Engine Chassis Feeding</td>
<td>48.00</td>
<td>1.00</td>
<td>48.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T28 Rear Arm To Frame</td>
<td>111.00</td>
<td>1.00</td>
<td>111.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T29 Drive Shaft Fitment</td>
<td>124.00</td>
<td>1.00</td>
<td>124.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total: 564.00 Sec.

### Station ID: Workstation 7

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models Options</th>
<th>ID Description</th>
<th>Qty</th>
<th>ID Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T30 Control Cable Fitment 1</td>
<td>169.00</td>
<td>1.00</td>
<td>169.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T31 Control Cable Fitment 2</td>
<td>142.00</td>
<td>1.00</td>
<td>142.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T32 Fuel Hose Fitment</td>
<td>281.00</td>
<td>1.00</td>
<td>281.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total: 592.00 Sec.
Station ID: Workstation 8

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty.</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T33 End of Line Inspection</td>
<td>14.00</td>
<td>1.00</td>
<td>14.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T34 Rolling Rod</td>
<td>195.00</td>
<td>1.00</td>
<td>195.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T35 Emission Analysis</td>
<td>44.00</td>
<td>1.00</td>
<td>44.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T36 CO &amp; Oil Temperature</td>
<td>139.00</td>
<td>1.00</td>
<td>139.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

![Time – Station Bar Chart for a Takt Time of 526.9seconds](image)

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Workstation 1</td>
<td>422</td>
<td>422</td>
<td>80.00</td>
<td>1</td>
<td>104.90</td>
</tr>
<tr>
<td>Workstation 2</td>
<td>509</td>
<td>509</td>
<td>97.00</td>
<td>1</td>
<td>17.90</td>
</tr>
<tr>
<td>Workstation 3</td>
<td>503</td>
<td>503</td>
<td>95.00</td>
<td>1</td>
<td>23.90</td>
</tr>
<tr>
<td>Workstation 4</td>
<td>491</td>
<td>491</td>
<td>93.00</td>
<td>1</td>
<td>35.90</td>
</tr>
<tr>
<td>Workstation 5</td>
<td>459</td>
<td>459</td>
<td>87.00</td>
<td>1</td>
<td>67.90</td>
</tr>
<tr>
<td>Workstation 6</td>
<td>452</td>
<td>452</td>
<td>86.00</td>
<td>1</td>
<td>74.90</td>
</tr>
<tr>
<td>Workstation 7</td>
<td>471</td>
<td>471</td>
<td>89.00</td>
<td>1</td>
<td>55.90</td>
</tr>
<tr>
<td>Workstation 8</td>
<td>412</td>
<td>412</td>
<td>78.00</td>
<td>1</td>
<td>114.90</td>
</tr>
<tr>
<td>Workstation 9</td>
<td>516</td>
<td>516</td>
<td>98.00</td>
<td>1</td>
<td>10.90</td>
</tr>
</tbody>
</table>
Table 13. Task in Each Workstation for a takt time of 526.9 seconds

<table>
<thead>
<tr>
<th>Takt Time: 526.9 Sec.</th>
<th>Total Line Time: 4235 Sec.</th>
</tr>
</thead>
</table>

Station ID: Workstation 1

<table>
<thead>
<tr>
<th>Processes</th>
<th>Required Resources</th>
<th>Required Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oper. ID</td>
<td>Description</td>
<td>Net (Sec.)</td>
</tr>
<tr>
<td>1</td>
<td>T1 Engine Unpacking</td>
<td>32.00</td>
</tr>
<tr>
<td>1</td>
<td>T2 Exhaust / Muffler Fitment</td>
<td>138.00</td>
</tr>
<tr>
<td>1</td>
<td>T3 Drive Shaft Fitment</td>
<td>91.00</td>
</tr>
<tr>
<td>1</td>
<td>T4 Air Box Fitment</td>
<td>62.00</td>
</tr>
<tr>
<td>1</td>
<td>T5 Front Cross Member</td>
<td>61.00</td>
</tr>
<tr>
<td>1</td>
<td>T6 Gear Oil</td>
<td>38.00</td>
</tr>
<tr>
<td></td>
<td>Total: 422.00 Sec.</td>
<td></td>
</tr>
</tbody>
</table>

Station ID: Workstation 2

<table>
<thead>
<tr>
<th>Processes</th>
<th>Required Resources</th>
<th>Required Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oper. ID</td>
<td>Description</td>
<td>Net (Sec.)</td>
</tr>
<tr>
<td>1</td>
<td>T7 Chassis Preparation</td>
<td>218.00</td>
</tr>
<tr>
<td>1</td>
<td>T8 Rear Suspension Fitment</td>
<td>109.00</td>
</tr>
<tr>
<td>1</td>
<td>T9 Brake Hose Fitment</td>
<td>109.00</td>
</tr>
<tr>
<td>1</td>
<td>T10 Shock Absorber</td>
<td>73.00</td>
</tr>
<tr>
<td></td>
<td>Total: 509.00 Sec.</td>
<td></td>
</tr>
</tbody>
</table>

Station ID: Workstation 3

<table>
<thead>
<tr>
<th>Processes</th>
<th>Required Resources</th>
<th>Required Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oper. ID</td>
<td>Description</td>
<td>Net (Sec.)</td>
</tr>
<tr>
<td>1</td>
<td>T11 Hand Brake Cable Fitment</td>
<td>140.00</td>
</tr>
<tr>
<td>1</td>
<td>T12 Hand Brake Drum Fitment</td>
<td>58.00</td>
</tr>
<tr>
<td>1</td>
<td>T13 Repositioning Chassis</td>
<td>139.00</td>
</tr>
<tr>
<td>1</td>
<td>T14 Packaging Back Frame</td>
<td>166.00</td>
</tr>
<tr>
<td></td>
<td>Total: 503.00 Sec.</td>
<td></td>
</tr>
</tbody>
</table>

Station ID: Workstation 4

<table>
<thead>
<tr>
<th>Processes</th>
<th>Required Resources</th>
<th>Required Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oper. ID</td>
<td>Description</td>
<td>Net (Sec.)</td>
</tr>
<tr>
<td>1</td>
<td>T15 Front - Suspension -1</td>
<td>274.00</td>
</tr>
<tr>
<td>1</td>
<td>T16 Front - Suspension -2</td>
<td>129.00</td>
</tr>
<tr>
<td>1</td>
<td>T17 Front Brake Hose Connection</td>
<td>65.00</td>
</tr>
<tr>
<td>1</td>
<td>T18 Horn</td>
<td>23.00</td>
</tr>
<tr>
<td></td>
<td>Total: 491.00 Sec.</td>
<td></td>
</tr>
<tr>
<td>Oper. ID</td>
<td>Description</td>
<td>Net Time (Sec.)</td>
</tr>
<tr>
<td>----------</td>
<td>------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>1</td>
<td>T19 Handle Bar</td>
<td>65.00</td>
</tr>
<tr>
<td>1</td>
<td>T20 Brake Fluid Topping &amp; Bleeding</td>
<td>113.00</td>
</tr>
<tr>
<td>1</td>
<td>T21 Brake Fluid Topping &amp; Bleeding</td>
<td>140.00</td>
</tr>
<tr>
<td>1</td>
<td>T22 Brake Fluid Topping &amp; Bleeding</td>
<td>141.00</td>
</tr>
<tr>
<td></td>
<td>Total: 459.00 Sec.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty.</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T23 Head Lamp Fitment LHS</td>
<td>87.00</td>
<td>1.00</td>
<td>87.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T24 Head Lamp Fitment RHS</td>
<td>73.00</td>
<td>1.00</td>
<td>73.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T25 Head Lamp Fitment - 3</td>
<td>123.00</td>
<td>1.00</td>
<td>123.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T26 Control Cable Fitment1</td>
<td>169.00</td>
<td>1.00</td>
<td>169.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 452.00 Sec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty.</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T27</td>
<td>Engine Feeding Engine Chassis</td>
<td>48.00</td>
<td>1.00</td>
<td>48.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T28 Control Cable Fitment 2</td>
<td>142.00</td>
<td>1.00</td>
<td>142.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T29 Fuel Hose Fitment</td>
<td>281.00</td>
<td>1.00</td>
<td>281.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 471.00 Sec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty.</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T30 Rear Tyre Fitment</td>
<td>301.00</td>
<td>1.00</td>
<td>301.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T31 Rear Arm To Frame</td>
<td>111.00</td>
<td>1.00</td>
<td>111.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 412.00 Sec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Station ID: Workstation 9

<table>
<thead>
<tr>
<th>Oper. ID</th>
<th>Description</th>
<th>Net Time (Sec.)</th>
<th>Take Rate</th>
<th>Wt. Time (Sec.)</th>
<th>Work Zones</th>
<th>Models</th>
<th>Options</th>
<th>ID</th>
<th>Description</th>
<th>Qty.</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T32 Drive Shaft Fitment</td>
<td>124.00</td>
<td>1.00</td>
<td>124.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T33 End of Inspection Line</td>
<td>14.00</td>
<td>1.00</td>
<td>14.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T34 Rolling Rod</td>
<td>195.00</td>
<td>1.00</td>
<td>195.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T35 Emission Analysis Oil Temperature</td>
<td>44.00</td>
<td>1.00</td>
<td>44.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>T36 CO &amp; Oil Temperature</td>
<td>139.00</td>
<td>1.00</td>
<td>139.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

References