

A Case Study on Implementation of Walking Worker Assembly Line to Improve Productivity and Utilisation of Resources in a Heavy Duty Manufacturing Industry

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The current industry demands high productivity removing every constraint inherited during manufacturing a product with limited resources. Re-configurability and Flexibility to produce multiple components depending on customer demand is a key factor. This projects aims at optimizing the productivity of a discrete heavy duty manufacturing company which adopts a Fixed-Worker-Assembly-Line (FWAL) to manufacture multiple products. The dynamic nature of heavy duty manufacturing assembly line is improved by converting FWAL into a Walking-Worker-Assembly-Line (WWAL). The productivity of proposed WWAL is calculated using ProModel simulation software and compared with FWAL to ensure optimization. Better utilization of resources and reduction of WIP is carried out in WWAL in order to generate an optimized and dynamic manufacturing unit and establish a common set of rules in converting a FWAL into WWAL.

Keywords: Simulation, Cycle time, Productivity, Assembly Line, Heavy duty manufacturing industry

1. INTRODUCTION

An assembly line is a Manufacturing Tool, first made by Henry Ford in his manufacturing of automobiles. An Assembly Line is a progressive system where semi-finished products from every stage move in line. Assembly lines are classified into three major types namely, (i) single model assembly line (ii) multi model assembly line (iii) mixed model assembly line. The assembling tasks of a single product are performed by workers in a single line until it's manufactured. In a multi-model assembly line, assembling tasks of various products are grouped and performed, in order to manufacture various products. Assembling tasks of multiple products are performed in batches, in order to manufacture similar products in mixed model assembly line [1]. A WWAL is a flexible, dynamic, and reconfigurable assembly system. Here, the workers are made to walk in between workstations laid out in desired layout to carry out the task assigned at each workstation [2]. In fixed worker assembly line, the worker remains static to carry out the operation specified and the product moves down the line according to the process flow [3]. Every company aims to produce more products with lesser workforce. We need a dynamic manufacturing unit to match the market demands. A WWAL is an upcoming technique

which employs ultimate utilization of resources. An analysis of a case study involving conversion of Fixed-Worker-Assembly-Line (FWAL) to Walking-Worker-Assembly-Line (WWAL) is employed to draft a generalized conversion algorithm. We have emphasised on how the human resource flow and allocation of work are instrumental in attaining an optimized WWAL. A Lean Manufacturing company basically targets the reduction of Work-In-Progress (WIP) at every stage. WIP is defined as the amount of work left in the semi finished product. We have studied how WWAL incorporates better worker utilization and reduction of WIP [4]. In this paper, we are going to focus on optimization of manual mechanical assembling. Conversion of current Fixed Worker Assembly Line (FWAL) Line to Walking-Worker-Assembly-Line (WWAL) to generate a lean adopted manufacturing unit with improved productivity.

2. RELATED WORK

In modern day industries, most of the companies manufacture a variety of products. We need a dynamic manufacturing unit to match the production demands. A FWAL for manufacturing discrete heavy duty products have numerous disadvantages. The assembly line is rigid and cannot be re-configured in order to match the production demands. There is no flexibility as it is difficult to manufacture a variety of products in a FWAL. The advantages of a WWAL over FWAL is studied and analysed to prove that WWAL has improved flexibility and re-configurability. Flexibility in an assembly system is the key factor required in any

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scenario and approximately 40% of capital cost is assigned to assembly unit and upto 50% in a manual assembly unit and optimizing an assembly line is a key factor that influences the efficiency of a manufacturing unit. Improvement on ergonomics in a WWAL to prevent injuries and enhance working conditions and optimize production. Comparison between FWAL and WWAL is studied and the parameters that define them are interpreted. Three phases for designing a WWAL, modelling, simulation and optimization are derived and a simulation study to prove WWAL works better than FWAL. There exists an optimized WWAL which is not optimized and doesn't integrate human resource performances and ergonomics to enhance productivity. Fluctuating current market demands flexible and reconfigurable assembly system. Disadvantages resulting from non-integrated design approaches in WWAL can include: greater operating costs economically and ergonomically and a duplication of design efforts. A frame work to design a WWAL is listed and two major steps in designing the framework are structural design level which involves determining the physical assembly line layout and operational design level which optimises the staff workers for the system and the specified skill levels for responding to the demand. Integration of flexible workforce and framework of layouts yields an optimized WWAL [5]. The manning of human resource in an assembly line improves flexibility. In a WWAL, there are fewer workers than workstations on the line. This dynamic, flexible and re-configurable system is called walking worker assembly line (WWAL). The workers travel to different workstations to perform the assigned task in order to manufacture the products. When there is congestion of workers with more task time at a particular workstation, it is called as bottle neck workstation. A Mathematical model is generated considering the ergonomic analysis and the constraints in a WWAL [6]. The assembly line systems and the variability in an assembly line are defined and the line balancing problems and worker classifications are studied as a linear layout of WWAL is interpreted and studied thoroughly incorporated in a case study in automobile assembly operations with 40 workstations and 4 buffers by simulation. The designed WWAL is implemented using Siemens software which aims at optimizing productivity of manual assembly line [7]. Methodology adopted to generate an optimized production line are, as-in-study-product selection-time method, Analysis-assembly line balancing-operational analysis, System evaluation-performance evaluation of product selection using ABC classification (selection based on importance), part process matrix (selection using product parts requirement). Different layout types in an assembly line are interpreted and motion economy principles are to be considered while optimizing an assembly line. The 3-step productivity is applied in a mobile phone package industry. Single stage parallel line' and Five stage serial line 'configurations are produced and simulated using Witness simulation software [9]. The tools and system adopted in designing a manufacturing unit for ergonomics and time optimization in a Railway coach

manufacturing scenario is designed into 3 phases, assembly line sequencing using Delima Quest software, an index to evaluate designs and flow value analysis, workplace assembly and ergonomics analysis using human modelling software Jack5.0, find bottlenecks, JIT, in current network, make improvements either in 'arrangement of work stations 'along line production or in complete product utilization [8].

3. PROCESS PARAMETERS FOR CONVERSION OF FWAL INTO WWAL

The conversion requirement and the way of conversion is explained in Fig.1 process flow chart, where we have embraced enhancement of critical parameters of an assembling unit and achieve an optimized lean adopted assembling unit.

1. The current FWAL is scrutinized in order to find the scope for optimization and the constraints to be satisfied are determined.
2. Data collection is done in order to determine the productivity of FWAL.
3. Conversion of FWAL into WWAL is achieved by grouping operating tasks that are either similar or that share a common inventory or both.

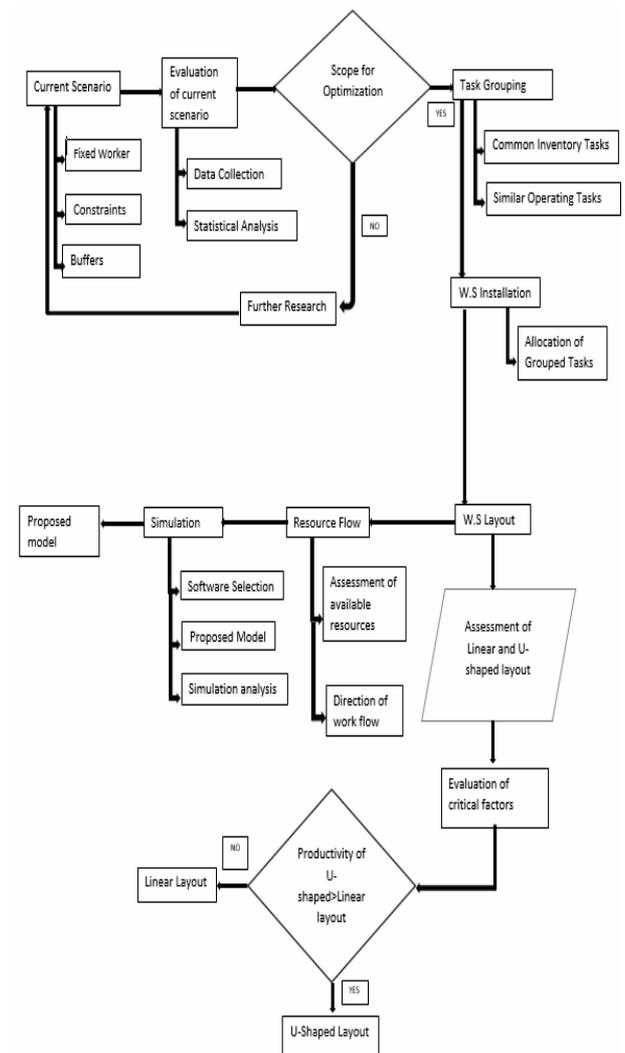


Figure 1. Process flow diagram for generalised conversion

4.The number of workstations will depend on the number of products to be manufactured. The grouped tasks are assigned to respective workstations according to the process flow. The allocation of machines depends on demand level and operation time.

5.The workstations are placed in a desired layout such that, the layout that suits the production plant and other constraints that are incorporated.

6.The workers are made to walk in the layout designed to perform the assigned task at their respective workstations. The directional of work flow and the path network for resources to move are defined.

7.Bottle neck analysis of WWAL is employed in order to determine the effectiveness of the proposed system.

8.Bottle neck analysis yields whether a station is idle or congested using equation 1. A positive value yields to work station idle time whereas, a negative value yields an in-process waiting time.

$$\left\{ \left(\sum_{x \in X} Ot_x + \sum_{x \in X} Wt_x \right) - \left(\sum_{x \in X} Ot_{x+1} \right) \right\} \quad (1)$$

9.Optimization analysis of WWAL espouses a lean adopted manufacturing unit as it eliminates the buffer zones and reduces WIP.

10. The number of workers will be less than the number of workstations.

11.Situational analysis of WWAL using appropriate software to enhance optimization results. Simulational analysis helps us achieve desired precise results [9].

4. OPTIMIZATION BY WWAL

4.1 Assessment of Current Scenario (FWAL)

The discrete heavy duty manufacturing company embraces a Fixed Worker Assembly Line, where the workers stay in a place to assemble a single product, until it being completely manufactured. The machines manufactured here are majorly grouped into two categories namely, Frequency Machines (FM) and Profitable Machines (PM). There are further, automatic and manual operating machine types in each group which are to be assembled. The constraints in the production system are obtained and assessed. Further the Buffer zones involved in the system are evaluated and optimized.

4.1.1 Constraints

The following are the constraints predefined and adopted throughout the project:

1. A minimum of two workers are necessary to assemble part of the machine
2. A minimum of two workers are necessary to carry parts from inventory to working area.
3. We aren't optimizing task buffer time now as it requires further ergonomic study.

4.1.2. Buffer

Buffer includes all the activities and tasks that add up to the cycle time and decrease the productivity. There

are two types of buffer in current manufacturing system namely task buffer and stage buffer.

(i)Task buffer: The buffer time involved in every activity incorporated while assembling is defined as the task buffer.

Table 1. Notations for buffer activity

Activity	Notation	Buffer activity
base buffer	Tba, Tbb	leg tapping changeover & painting
bed buffer	Tma, Tmb	x bed and y bed changeover
cutting arm buffer	Tca., Tcb, Tcc, Tca	changeover from block to base assembly
z bed buffer	Tza	feed movement screws
cover assembly buffer	Tca	unit screws of varied size
coolant buffer	Twau	lower steel rod attachments
door buffer	Tda	door nuts and screws pickup
coolant tank buffer	Tcta	tank pick up and setting
bearing buffer	Tbh	varied size tools
bearing housing buffer	Tbha	varied tools for fixing
automatic buffer	Tabh, Tabw	varied tools and attachments

(ii)Stage buffer: These include the tool change and changeover time from one activity to another, for example from base assembly tools to x-y bed tools.

4.2 Data Collection

Collection of data is an important part in case study analysis while proposing an optimized production system. The collected data are grouped into the following tabular columns for analysis.

Table 2. Task buffer time (mins)

Activity	Task buffer	PM M	PMA	FMA/ M	FMA/ M2	FMA/ M3
Base	T _{ba}	6	6	4	2	2
	T _{bb}	5	5	4	-	-
x-y-bed	T _{ma}	5	5	4	2	2
	T _{mb}	5	5	4	2	-
Cutting	T _{ca}	4	4	4	2	2
	T _{cb}	3	3	4	-	-
	T _{cc}	5	5	-	-	-
	T _{cd}	2	2	-	-	-
Z-Bed	T _{za}	7	20	4	2	2
Cover Assembly	T _{ca}	2	2	4	2	2
Coolant	T _{wau}	2	2	4	2	-
Door	T _{da}	2	2	4	2	-
Tank	T _{cta}	2	2	4	2	-
Bell	T _{bh}	2	2	2	2	-
Bearing	T _{bha}	2	2	2	-	-
Auto	T _{abh}	10	10	3	4	2
	T _{abw}	10	10	-	-	-

Index: PM-profit machines, FM-frequency machines, A-automatic machines, M-manual machines.

Table 3. Tasks Operating Time (PM&FM) (mins)

	PM/FM	PMM	PMA	FMA/M	FMA/M	FMA/M
1	Base	2	3	4	5	1
2	x-y-bed	2	3	4	5	1
3	Cutting	2	3	4	5	1
4	z-bed	2	9	4	5	1
5	Cover	2	3	4	5	1
6	assembly Coolant	2	3	4	5	1
7	Door	2	3	4	5	1
8	Tank	2	3	4	5	1
9	Bearing	2	3	4	5	1
10	Auto	2	3	4	5	1

4.3 Calculation of Current Productivity: Statistical Analysis

The following section deals with the analysis and simulation of WWAL for the system.

4.3.1. Operation time: The amount of time that is needed for the two workers to perform the tasks assigned.

4.3.2. Cycle time: The amount of time required to assemble a product completely including every possible buffer. In this case study, one cycle of production yields five machines.

Formulae used:

$$T, B(n) = \sum_{x \in X} T_x \tag{2}$$

$$S, B(n) = \sum_{x \in X} T_{x-x+1} \tag{3}$$

$$O, T_x(n) = \sum_{x \in X} E_x \tag{4}$$

$$C, T(n) = \frac{\sum T_x + \sum T_{x-x+1} + \sum OT_x}{\beta} \tag{5}$$

$$C, T(n) = (M, T + O, T(x) + T, B(n) + S, B + C, T) / \beta \tag{6}$$

4.4 Task Grouping

Grouping of similar tasks is the next step in conversion. For instance the base production of all machines is grouped. In this case, we have five machines whose assembling tasks are similar. There are ten assembling tasks for each machine to be grouped.

4.5 Workstation Installation & Allocation of Work

The next major step is creating workstations in which the grouped tasks are to be carried out. We are creating five workstations as five machines are to be manufactured. The grouped tasks are assigned to specified workstations.

4.5.1 Human Resources Available For Machines Which are to be Distributor

The available human resources to be considered in our production model are:

- Mechanical Assembly : 2
- Sub Assembly : 4

Every workstation involves assembly activity of a single machine and allocation of work is defined by

resource flow. The allocations of machine order are based on demand level and operation time.

4.6 Proposed Layout

The workstations are placed in a U-Shaped layout as demonstrated in Fig.2, in the production floor. The five machines are placed in five workstations in the U-Shaped layout. The number of workers will be less than the number of workstations [10]. The workers are made to walk in between these workstations to perform the tasks assigned. As the distance between the workstations is uniform and small, it assists a visual feedback system. A visual feedback system is when workers in a workstation can seek help from workers of nearer workstations and convey information in case of an emergency or failure. D is the distance between the workstations and V is the speed of workers. The D value is calculated to be 0.32 m and V to be 2m/s.

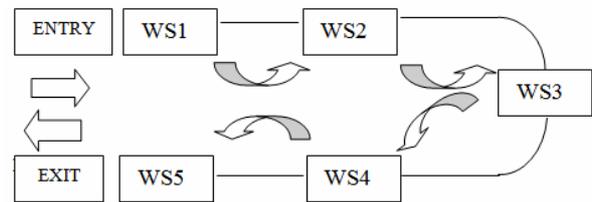


Figure 2. Workstation layout of WWAL

4.7 Bottle Neck Analysis

Congestion of workers before the workstation is called as bottle neck. Bottle neck analysis yields workstation 3 as bottle neck workstation as there is a task that involves 9 min of assembling that makes the workers of previous workstation to wait and downtime production at the bottle neck workstation. Bottle neck analysis yields whether a station is idle or congested [11].

4.8 Resource Flow

Workers are made to walk in between multiple U-Shaped workstations and perform the allocated tasks. Workers are made to walk unidirectional unless an emergency situation is called. Two workers begin the operation at first workstation, on their completion they move to the next workstation. The next two workers enter that workstation now to complete the next procedural task progressively. Speed of workers is assumed to be 2m/s.

4.9 Optimization Analysis

Lean adopted manufacturing unit is generated as it eliminates the stage buffers and reduction of WIP at every workstation. We are manufacturing five machines which are majorly classified into two types. Ten tasks are carried out in order to generate a completely manu-factured component. For every machine assembling, minor arrangements have to be made in order to perform the next machine's task which includes 'machine setting' and 'tool change'. The total of ten stage buffer zones for every component and fifty stage buffer zones for all 5 machines

exist in current scenario. The proposed system consists of five workstations where five machines to be assembled are placed. The five machines share common tasks but different tools and minor arrangements in their settings. The similar task of every product is carried out in five stations by the walking workers, in their first run and the next similar task in their next run and goes on progressively. This ensures elimination of stage buffer zones and minimizes it into ten stage buffer zones from fifty in the proposed scenario as the tool changes and minor arrangement settings are required only when dissimilar tasks are carried out.

4.10 Simulation Model Of Proposed System

Simulation of the proposed system is incorporated to demonstrate the optimization of worker utilization and increase in productivity. We have used ProModel software to carry out the simulation.

1. Build Menu allows access to define the major elements namely: Locations, Entities, Arrivals, Processing, and Resources.
2. Eleven locations are created in which the WS locations are where the operations are carried out whose capacities are one and five barrel locations with infinite capacity and inventory locations are defined.
3. Five entities which are the five machines to be manufactured are defined.
4. Arrival cycle is defined as shown in Fig.3, for the entities to enter the location in scheduled order.
5. Arrival cycle is defined as shown in Fig4, an called in the arrivals menu.
6. Path network of the resource worker is defined. Here, the 'distance between the workstations', 'unidirectional flow of resources', and 'non-passing type' path are defined as dshown in Fig5.
7. *Index*: One worker does the activity of two.

Two resources are defined as shown in Fig.6, where one worker operate in a single workstation as the capacity of workstations are limited to one.

8. Processing routing is defined and the barrel locations are indicated in order to store the ten assembling tasks and then route to exit. Fig.7, shows the processing logic defined for execution of assembling tasks.

- Operations defined are, (i) *USE<Worker> FOR<x mins>* (ii) *WAIT<x hr>*
- Move logic used, (i) *MOVE WITH<Worker>FOR<x mins>THEN FREE*

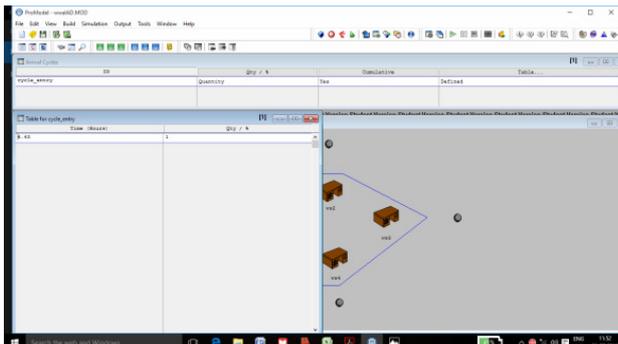


Figure 3. Arrival cycle defined for the entities to flow in.

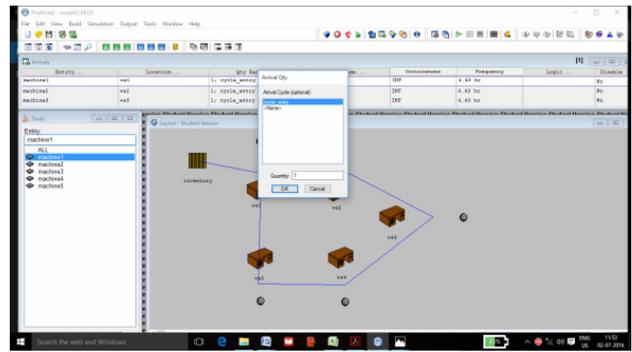


Figure 4. Arrivals process where it calls the defined arrival cycle for structured entity flow

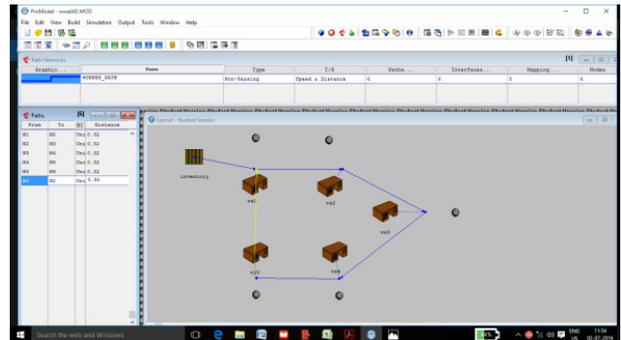


Figure 5. Path Network defined for workers to move in and the direction of flow to ensure proper worker allocation and walking time calculation.

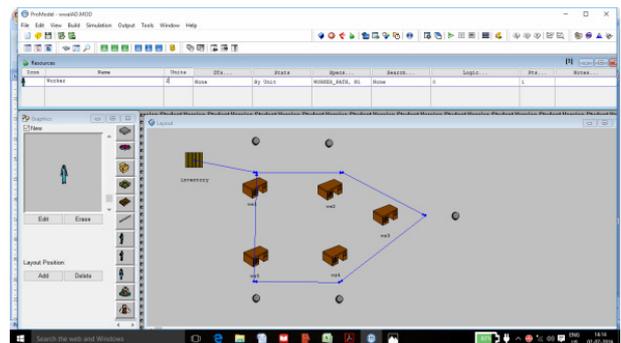


Figure 6. Resources to be moved in the path network are defined and called here.

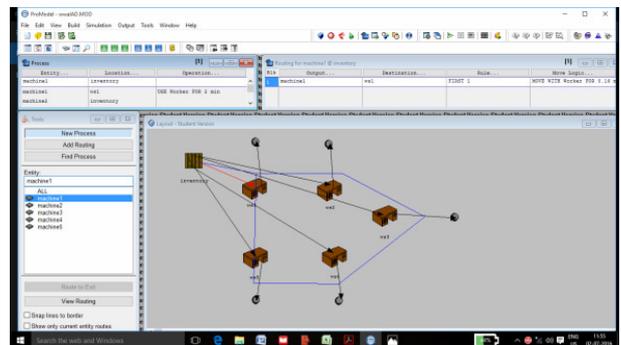


Figure 7. Processing step is where you define the flow of operation for execution.

5. RESULTS AND DISCUSSIONS

In our case study, one cycle of production yields five machines. The total number of working days for an employee in the company is for 261 days and the number of working hours per day is 8 hours.

No. of machines produced per year= No. of working hours in a year/ C.T (n)

There is a reduction of cycle time considerably in the proposed WWAL as shown in Fig8, which compares the cycle time of current model and proposed model. The buffer zones involved in both the models are compared in Fig.9, which shows the dynamic nature of WWAL and reduced buffer time that enhances productivity and assists a dynamic assembling unit.

Table 4. Calculation results (fatigue value $\beta=0.97$)

Statistical Parameters	FWAL (min)	Simulated parameters	WWAL (min)
Task Buffer	248	Task Buffer	248
Stage Buffer	550	Stage Buffer	246
Operation Time	266	Operation Time	266
		Worker waiting time	15.6
		Moving Time	243

Table 5. comparison results

Productivity	FWAL	WWAL
C.T (n)	18.27 hrs	16.6 hrs
Number of machines	570	625

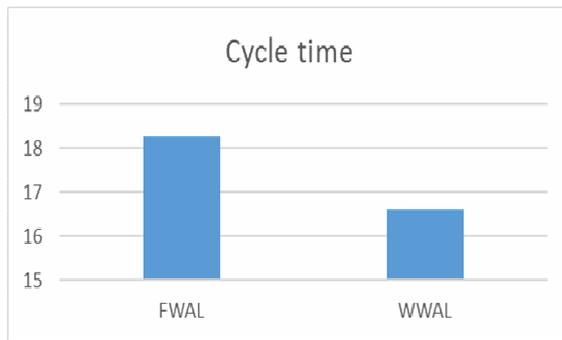


Figure 8. Graphical representation for comparing the cycle times between FWAL and WWAL.

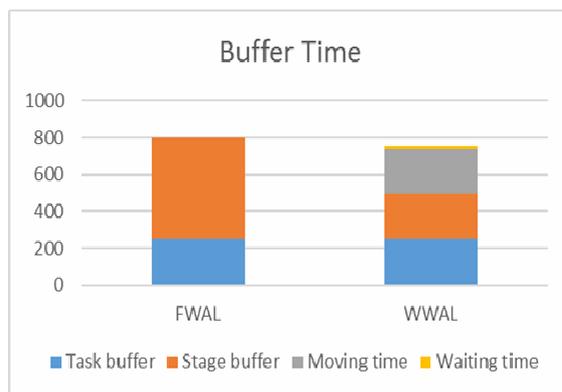


Figure 9. Graphical representation of all buffer times in FWAL and WWAL

6. CONCLUSION

The proposed WWAL model can serve as an aid to the heavy duty manufacturing industries by reducing cycle time and improving the productivity. This model can be further implemented in other types of manufacturing industries that employ bulky conveyors for production. The algorithm elucidated above in this research paper

for converting Fixed Worker Assembly Line to Walking Worker Assembly Line was verified with the help of a virtual model simulated using Promodel software.

As future research, the impact of ergonomic factors and working condition parameters that will keep varying when the workers keep moving between every workstation in the assembly line can be analyzed and the performance of the Walking Worker Assembly Line can be enhanced further.

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**СТУДИЈА СЛУЧАЈА ФЛЕКСИБИЛНЕ
МОНТАЖНЕ ЛИНИЈЕ У ЦИЉУ
ПОБОЉШАЊА ПРОДУКТИВНОСТИ И
ИСКОРИШЋЕЊА РЕСУРСА У ТЕШКОЈ
ИНДУСТРИЈИ**

А. Деепак, Р. Сриватсан, В. Самсингх

Један од захтева данашње индустрије је висока продуктивност која елиминише сва ограничења производње која намећу ограничени ресурси. Кључни фактори су реконфигурабилност и флексибилност процеса производње сложених делова према захтевима купаца. Циљ пројекта је оптимизација продуктивности одређене компаније која се бави производњом машина и која има систем нефлексибилне монтажне линије, тј. без кретања радника поред траке. Динамика монтажне линије за производњу машина се повећала преласком на флексибилни систем. Продуктивност је израчуната помоћу ProModel софтвера и извршено је поређење са нефлексибилним системом да би се обезбедила оптимизација. Код флексибилног система постигнута је боља искоришћеност ресурса и редукација трајања радног процеса како би се произвела и оптимизирала производња компоненте и установио низ правила за прелазак са нефлексибилне на флексибилну монтажну линију.