Production Line Balancing using Video based Line Balancing Software

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Abstract – *In modern manufacturing world, the utilization of all available recourses plays a major role. And hence the objective of line balancing is even distribution of tasks to all workstations so that all the resources available can be effectively utilized. These challenges can be overcome via the video-based line balancing software as it is accurate and quick so it increases the accuracy in data collection and also reduces the time for the study. The project focuses on an industrial case of line balancing of the crankcase production line. The foremost objective is achieved by Yamazumi chart and man-machine chart. Time study has been done using video-based line balancing software Timer-pro to identify operator utilization and idle time (Non-value-added activity).These two tools are used in this paper to identify operator utilization and idle time of operator and machine along with idle time utilization.*

***Key Words*: Operator Utilization, Yamazumi Chart, Man-Machine Chart, Line Balancing, Timer-Pro Video based Line Balancing Software.**

1. INTRODUCTION

Now a day's every manufacturing industry wants to identify whether all the resources provided on the production line and assembly line are effectively utilized or not, owing to global competition industries want to produce their product at a cheapest price. So human recourses management is an important factor for the whole manufacturing industry. Assembly line or production line balancing is even allotment of task to all over workstations provided online. Various tools and techniques are used to balance assembly or production lines but these tools and techniques do not identify effective utilization of operators on the production line or assembly line. Now a day's video-based line balancing software is used, this line balancing software's not only collect accurate time data but also provides various other lean manufacturing tools and techniques. From the previous research work in operator utilization various computer modeling and simulation software are used. These simulation techniques consist of a comparison of indicators before and after. In that similar way, the video-based time study software works. The software used in the present study is Timer-pro software. But the advantage to use this time study software is that time study data collected in the form of video is feed to this software so the accuracy of time study data increases drastically. As the assembly line or production line consists of numerous tasks so it is very difficult to collect the data with the help of a stopwatch or any other traditional method. Also, the task time varies from operator to operator as the human skills of doing tasks vary. Owing to all these complications and restrictions video-based time study software is the most suitable option.

According to Rohana Abdullah *et al* 2014[1] "Manufacturing organization with an increase in the organizational complexity, is facing difficulty in measuring its performance. Various factors could affect manufacturing performance such as equipment performance, material planning, and human resources" so nowadays as technology is budding it is very important to know for manufacturing industries whether the operators, machines, and other equipment they use are effectively utilized or not. These industries have invested huge money in all these technology-driven equipment, robots, and also humans (operators).To know the effective utilization of every system in the manufacturing sector is a part of lean manufacturing because, during its study, it is easy to identify waste and eliminate it from the system. Wang Qian *et al* (2007) [11] developed a simulation model for a theoretical study into the linear WW system (Walking-Worker) using a manufacturing-focused simulation tool. The objective of this study is to observe the relevant impact of logical interactions and the number of walking workers against the system performance. This simulation model gives output between linear fixed workers and the number of walking workers and the impact of these parameters on system performance.Ghada Elnaggar (2019) [3] studied the effect of operator skill level on assembly line balancing. This study was carried out with the help of a simulation model; an optimization experiment was conducted to find the best number and distribution of resources to obtain minimum completion time and maximizing utilization of all resources. The results obtained from this study show that how operator skill affects the assembly line balancing problem because operator skill level affects the completion time of tasks or work which ultimately affects the total output. Also, this operator skill level greatly affects the distribution of work at each workstation. R.J.Curbano *et al* (2016)[2] presented an improvement of manpower utilization in the assembly line for sub line and the mainline 2.Stream Diagnostic Diagram is used to identify the main problems of the line due to high-work-in-progress, poor layout, low efficiency, and unbalanced processes. Cycle time and number of operators of the assembly lines are determined by time and motion study and line balancing. POM-QM software is used to validate these various alternatives. The final result gives, 10.53% increase in profit, and the efficiency of the line is increased by 17.39% for the main and subline.S.K.Subramaniam *et al* (2008) [10] this paper investigated that, the main factors contributing to production line efficiency are manpower utilization and machine efficiency. To measure these two factors the data should be on-line, accurate, and truthful. The management should look for the relevant production data and to accurately interpret this data to identify various faults at production and to take immediate steps to eliminate these faults. According to Hong-ying Shan *et al* (2013) [8], the operational efficiency of the assembly line or production line increases with the balance of production or assembly line. Computer modeling and simulation greatly shorten the R&D cycle, predict and optimize the production line layout. In this study author used Flexium software to model and simulate the U-gearbox assembly line. The results obtained are compared to the differences before and after simulation. The final result gives a reduced number of workstations, balance even load on workstations, and improved overall line efficiency. Muhammad Marsudi and Hani Shafeek (2014) [6] applied an analytical approach based on mathematical models to improve the utilization of the production line. The analytical approach used for this study is validated with the help of Arena simulation. The results of the study give improved resource utilization at the production line.R.J.Sury (1971) [9] carried out an examination based study with the help of computer-assisted simulation for conditions of perfect and imperfect balance between manual workstations. The result of this study gives increased operator utilization.Batool Ibraheem Jameel (2015) [5] carried out an experimental study of the effectiveness of the line balancing on production flow efficiency. Rank Positional Weights Method (RPW) is used to assign tasks to various stations. For practical, the discussion is carried out through eight cases where each case reflects one situation that can be applied to the production assembly line. The final results of the study show efficiency of line increases from 50% to 92% which represents good management of resources. Richard Hedman *et al* (2014) [4] identified relationships between operator utilization and real process capacity in the automated manufacturing industry. The author stated that there is constant interaction between humans and machines in the automated manufacturing industry. The utilization of these resources greatly affects the capacity of manufacturing processes and ultimately the performance of the manufacturing system. The result of this study shows that how productivity data regarding the utilization of both manual and equipment resources are measured and organized to improve real capacity. Bhaba.R.Sarker and Haixu Pan (1998) [7] designed a mixed-model assembly line to minimize the costs of idle and utility times. For this research a mixed-model assembly line either closed or open station is considered. The different parameters considered are launch interval, station length, the starting point of work, upstream walk, and locus of the operator's movement, etc. The results of this research showed that for a given length the total cost of utility and idle times is minimum in an open system. From the above research carried out in the field of operator and equipment utilization on production or assembly line, it is observed that various simulation techniques are used to identify operator utilization. Also, the performance of any manufacturing industry is greatly affected by its operator and other equipment utilization. Nowadays the variety in product increases and hence to satisfy variety in customer demand it is necessary to have multi-model and mixed-model production and assembly lines. But to carry out a line balancing study of all these multi-model and mixed-model production lines, the accuracy in time study data collection is an important part. Hence to maintain this accuracy of data video-based time study data collection method is preferable. Also, the operator skills greatly affects the task time. Hence during data collection considering the operator skills and variety in models of component the use of video-based line balancing software can be beneficial to all kinds of industries. There is not much research carried out in this field of video-based time study data collection and line balancing software.

This paper deals with an industrial case study of a R1040 Crankcase production line. So time data collection is done with the help of video-based time study software Timer-pro. Yamazumi chart one of the tools in timer-pro software is used to identify operator utilization at each workstation. After this identification, a man-machine chart is drawn for existing cells or workstations. This man-machine chart gives the idle time of the operator as well as the machine. Along with this, from time study data theoretical numbers of workstations are calculated. The Yamazumi chart and Man-machine chart of existing workstations or cells gives a clear idea of whether it is possible to reduce the workstations or not.

2. Problem Definition

Figure 2 represents an engine component production line consisting of different tasks from OP-001 to OP-235. The precedence relation among these different tasks is in a straight line figure 1 represents precedence relation among different tasks. The raw material of the Crankcase an undergoes various machining processes at different stations. Some of these stations are automatic and some stations are manually operated (manual deburring, air blowing, inspection, and assembly of components). From the line layout of crankcase production line in figure 2, it can be observed that these twenty-nine machines are divided into six cells, These six cells consists of each six operators. The production line layout is a C-type line layout and the cycle time is 360 seconds (6 Minutes). The raw crankcase casting is stored on roller conveyors and according to the customer demand the machine set-up is done for a particular model and its production process is carried out on the production line. There is variety in model of Crankcase; presently there are three models; (2,3,4-Cylinder)For this project, these models are designated as A, B, C.Out of these three models the 4-cylinder model is taken for study because this model consists of more number of machining/production operations than remaining two models and hence the machine auto time.

Figure 1 represents the precedence relationship among various tasks performed on the crankcase production line. Precedence constraint is the most important constraint in line balancing because the product cannot proceed to the next station unless and until the previous task is completed. These are the technological constraints applied to the component to convert it to the final finish product.

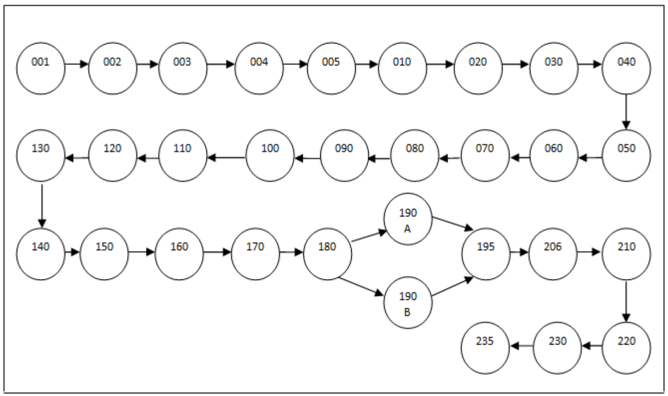

Figure 1: Network representation of Crankcase

Precedence relation gives an idea of how and when the various machining and manual tasks can be performed. The different operations performed on crankcase are designated from OP-001 to OP-235 as shown in figure 1. For the given problem, the precedence relation shows that there is straight relation among the various tasks performed on different machines only the difference lies at OP-190A and OP-190B. These are the two machines performing the same machining operations, but the cycle time of this operation is more than the bottleneck operation cycle time and hence these two same machines are placed parallel on the line to balance the production line. The task time for each task performed on the crankcase is given separately.

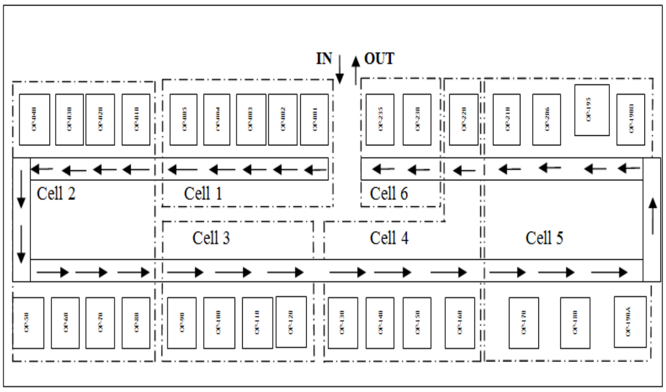

Figure 2: Crankcase Production 'C-Type' Line Layout

2.1 Purpose of Study and Methodology

This case study focuses on the industrial production line balancing problem. The present industry wants to identify the following points regarding engine component production line.

1. Operator utilization in each cell or at each workstation
2. Non-value added activities performed by the operator
3. It is possible to reduce the number of workstations

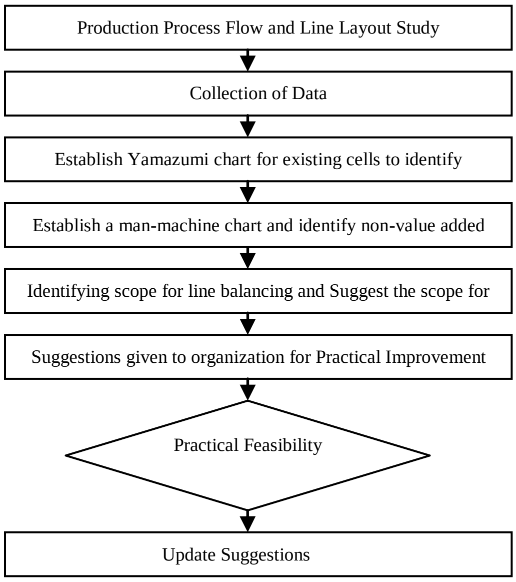

Figure 3: Methodology for this study

2.1.1 Production process flow and line layout study

The first step is the study of production process flow and the line layout understudy, Figure 3 represents the methodology adopted for this study. This step is very important for line balancing, as it is necessary to study the existing working process. This data includes the study of production line layout, number of cutting and non-cutting machines on line, material handling equipments, manual and auto work content, operator work sequence, etc. This data was collected by physically observing the production line. This data allows studying and understanding the production process deeply. All the minute details are noted and the value-added and non-value added activities performed by the operator are segregated.

2.1.2 Collection of Data

This is an important step in this study, for carrying out line balancing on the production line. This data may include operator task time at each workstation, operator walk time in a cell, machine auto time, and material handling equipment time. All this required data is collected through video-based time study software timer pro software. The operator task time is collected for two shifts and for two different operators at two different times (before lunch and after lunch) to increase the accuracy of the result. The average reading is taken as a final reading for study.

2.1.3Establishing Yamazumi chart for existing cells or workstations to identifying operator utilization

The time study data collected through videos is used to establish a Yamazumi chart in timer pro software. This Yamazumi chart is a very use full tool, as it gives a graphical representation of activities performed by the operator in each cell or workstation. This Yamazumi chart helps to identify operator utilization in each cell.

2.1.4Establishing Man-machine chart for existing cells or workstations to identifying non-value added activities performed by operator and machine

The time study data collected through videos is used to establish a Man-machine chart in timer pro software. This Man-machine chart is a very use full tool, as it gives a graphical representation of all the manual activities performed by the operator. All these activities may include value-added, required non-value added and non-value-added activities of man and machine in each cell or workstation. This Man-machine chart helps to identify operator and machine idle time (non-value-added) in each cell or workstation.

2.1.5 Identifying scope for line balancing and Suggest the scope for improvement opportunity

The man-machine chart is drawn for six numbers of workstations (existing cells) and the idle time of man and machine is analyzed, if the idle time of man is observed comparatively more with the bottleneck operation cycle time then there is scope for improvement. The Yamazumi chart also depicts the scope for improvement.

2.1.6 Suggestions Given to Organization for Practical Improvement

After analyzing the results obtained by using Yamazumi and Man-machine chart, some improvement suggestions are given to the organization.

2.1.7 Practical Feasibility Analysis of given Suggestions

The suggestions given for the improvement of the crankcase line are discussed and analyzed for the practical feasibility.

2.1.8 Update Suggestions

The suggestions given are checked fist for its practical feasibility. If it satisfies all required practical conditions then it is applied otherwise the suggestions can be updated according to practical feasibility.

3. Time Study Data For Given Problem

Time study data collection is an important part of data collection but the most important thing in this is the accuracy of collected data. The video-based time study data collection provides the facility to maintain accuracy in data collection. For the present study, the data is collected for two different working shifts (Before and after lunch), for two different operators. The final reading is taken as the average reading. This problem can be summarized in a tabular form in terms of the precedence relation is given in Table 1.

Table -1: Precedence relation and task times

Work Element	Immediate Predecessor	Activity Time (Sec.)
OP-001	-	110
OP-002	OP-001	86
OP-003	OP-002	29
OP-004	OP-003	32
OP-005	OP-004	63
OP-010	OP-005	25
OP-020	OP-010	52
OP-030	OP-020	35
OP-040	OP-030	23
OP-050	OP-040	55
OP-060	OP-050	23
OP-070	OP-060	61
OP-080	OP-070	58
OP-090	OP-080	24
OP-100	OP-090	22
OP-110	OP-100	32
OP-120	OP-110	239
OP-130	OP-120	32
OP-140	OP-130	46
OP-150	OP-140	18
OP-160	OP-150	26

OP-170	OP-160	22
OP-180	OP-170	33
OP-190A	OP-180	47
OP-190B	OP-180	62
OP-195	OP-190A/OP-190B	143
OP-206	OP-195	28
OP-210	OP-206	9
OP-220	OP-210	389
OP-230	OP-220	56
OP-235	OP-230	125

Table 1 represents the work element, immediate predecessor, and activity time in seconds. The activity time is the summation of manual activity time (Loading, Unloading, Press Striker button, etc.) All this time study data is collected with the help of video-based Timer Pro software. The manual activity time is taken per one component. The OP-190A and OP-190B are the same (top face finish milling and linear bore finish boring) machining operations but the machine auto time (cycle time) of this operation is 11.46 minutes and the bottleneck operation cycle time is 6 minutes. Hence to balance the line two parallel machines performing the same operation are installed on the production line.

3.1. Existing Cell wise Time study Data of Crankcase Production Line

The current industrial problem consists of six numbers of workstations. Table 2 gives the existing six-cell time data. The fifth cell is divided into two parts first is 5A and second is 5B, this is done because the OP-190A and OP-190B performs the same machining operation of top face finish milling and linear bore finish boring. Hence only one operator operates this cell alternatively for OP-190A and OP-190B.

Table -2: Existing 6 Cell Time Data

Cell NO.	Operation	Machine Auto time (Sec.)	Manual activity time (Sec.)	Total Manual activity time (Sec.)
1	OP-001	355	110	342
	OP-002	343	86	
	OP-003	331	29	
	OP-004	306	32	
	OP-005	366	63	
	Walk to OP-001 (Home Position)		22	
2	OP-010	323	25	335
	OP-020	333	52	
	OP-030	359	35	
	OP-040	330	23	
	OP-050	360	55	
	OP-060	335	23	
	OP-070	291	61	
	OP-080	315	58	
	Walk to OP-010 (Home Position)		3	
3	OP-090	362	24	341
	OP-100	358	22	
	OP-110	282	32	
	OP-120	234	239	
	Walk to OP-090 (Home Position)		24	
4	OP-130	349	32	332
	OP-140	338	46	
	OP-150	364	18	
	OP-160	243	26	
	OP-220 (One Manual Activity)		190	
	Walk to OP-130 (Home Position)		20	
5A	OP-170	322	22	285
	OP-180	329	33	
	OP-190A	688	47	
	OP-210,OP-195 and OP-206		180	
	Walk to OP-170 (Home Position)		3	
5B	OP-170	322	22	300
	OP-180	329	33	
	OP-190B	688	62	
	OP-210,OP-195 and OP-206		180	
	Walk to OP-170 (Home Position)		3	
6	OP-220	262	199	390
	OP-230	296	56	
	OP-235		125	
	Walk to OP-220 (Home Position)		10	
			Total Sum	**2040**

The current industrial problem consists of six numbers of workstations. Table 2 gives the existing six-cell time data. The fifth cell is divided into two parts first is 5A and second is 5B, this is done because the OP-190A and OP-190B performs the same machining operation of top face finish milling and linear bore finish boring. Hence only one operator operates this cell alternatively for OP-190A and OP-190B.

Theoretical Number of Workstations= $\sum_{w=1}^{w=15}$ Total manual activity time/Bottleneck operation cycle time = 5.66 ~ 6

For the above calculation, the bottleneck operation cycle time is 360 seconds. The overall sum of total manual activity in table 2 is 2040 seconds. Hence the theoretically calculated value of the number of workstations is six. So from the above- the theoretical calculated number of workstation are six and the existing number of workstations or cells on crankcase production line is also six. So at this stage, it is concluded that the number of workstations for the crankcase line cannot be reduced. But we need to identify operator utilization at each workstation or cell. To identify the operator utilization at each workstation or cell Yamazumi chart of operator utilization is prepared in time-pro time study software.

6. Yamazumi Chart for Existing Crankcase Production Line

Yamazumi chart is a graphical representation of manual activities performed by the operator at each workstation or cell. There are three or more than three colors used in this graphical representation, as these colors are designated to value-added (Green), non-value-added(Red), and required-non-value-added(Blue) activities performed by the operator. This graphical represents gives clear idea and visual graphical representation of all the manual activities performed by the operator. Operator or workstation utilization can be defined as, the percentage of time the workstation or operator is busy doing that operation or task.

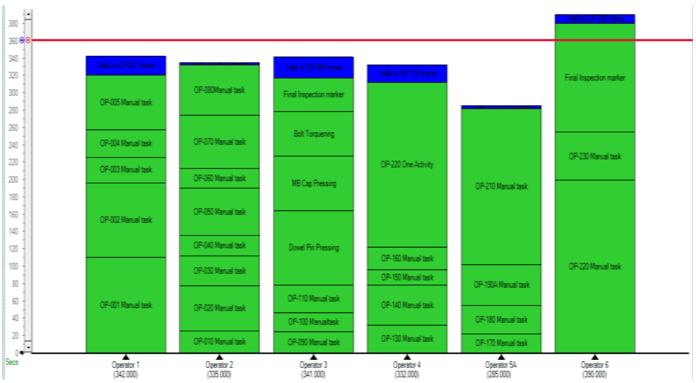

Figure 4: Yamazumi Chart for Existing Crankcase Production Line (5A Operator)

Figure 4 represents the Yamazumi chart for the Crankcase production line for considering operator 5A. It means operator number 5 in cell number 5 operates machine OP-190A.

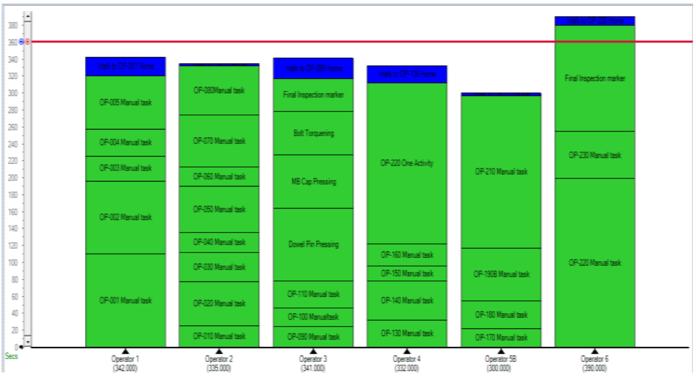

Figure 5: Yamazumi Chart for Existing Crankcase Production Line (5B Operator)

Figure 5 represents the Yamazumi chart for the existing crankcase production line considering operator 5B. It means operator number 5 in cell number 5 operates machine OP-190B. The horizontal red color line in two graphical figures numbers 4 and 5 represents the bottleneck cycle time for the crankcase production line. The bottleneck operation cycle time for the line is 6 minutes or 360 seconds. To balance this production line, all these manual activities need to be balanced up to 360 seconds. Considering the industrial requirement, the objective of this study is to identify operator utilization in each cell. The operator is utilized or loaded for manual work up to 80% to 95%. Hence considering for crankcase line the operator should be loaded for 332 seconds to 342 seconds. The Yamazumi chart in figure 4 and 5 shows that the cell 1 to cell 4 is quite balanced workstations. But the cell number 5 seems to be less loaded and cell number 6 is overloaded. So to balance these workstations, cell numbers 5 and 6 need to be considered. As the theoretical calculated value of workstations and existing number of workstations are same. But as we already discussed that operator number five in cell number five operates alternatively OP-190A and OP-190B machine, hence it is not possible to load that operator number 5. So the operator in cell number 6 needs to be balanced.

6.1. Man-Machine Chart for Crankcase Production Line

Man-Machine chart is an important tool in line balancing problems because it gives a clear representation of operator and machine idle time. Idle time of an operator or machine can be defined as it is the time for which the operator or machine has no work to do. It is a graphical representation in which the X-axis represents the operator and the number of machines operated by that operator in a particular cell or workstation. Y-axis represents the task time of the operator and machine auto (cycle) time. This section consists of a man-machine chart for crankcase production line all six cells or workstations. In this graphical representation of the Man-Machine chart, different colors are used according to the tasks or activities performed by the operator and machine. The following figures of the man-machine chart consist of green, red, and blue colors. Green color represents value-added activities (VA), red color represents non-value-added activities (NVA) and blue color represents required non-value-added activities (RNVA).

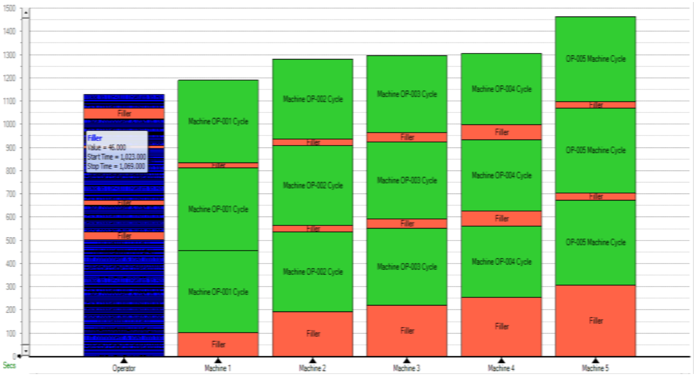

Figure 6: Man-Machine Chart for Cell No.1

This man-machine chart is drawn for two or more task operating cycles of the operator. Because it helps to identify the operator idle or machine idle time in repetitive cycles.

Figure 6 represents the man-machine chart of cell 1 of the crankcase line. In this cell 1, the operator operates five different machines from OP-001 to OP-005. Here it is observed that the Operator in cell 1 has an idle time of 46 seconds. As this operator is loaded more than 95% hence it is not possible to utilize this operator more.

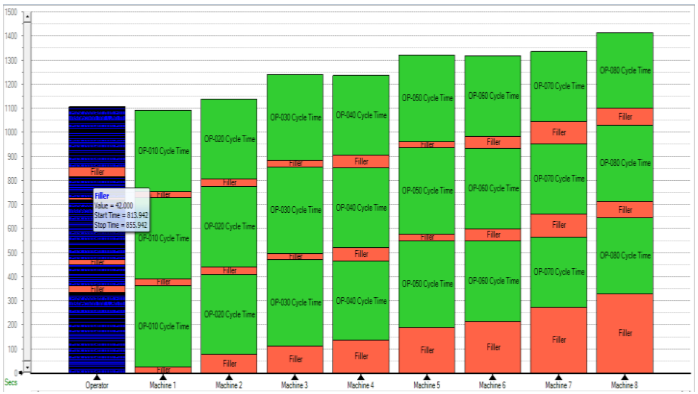

Figure7: Man-Machine Chart for Cell No.2

Figure 7 represents the man-machine chart of cell 2 of the crankcase line. In this cell 2, the operator operates eight different machines from OP-010 to OP-080. Here it is observed that the Operator in cell 2 has an idle time of 42 seconds. As this operator is loaded more than 90% hence it is not possible to utilize this operator more.

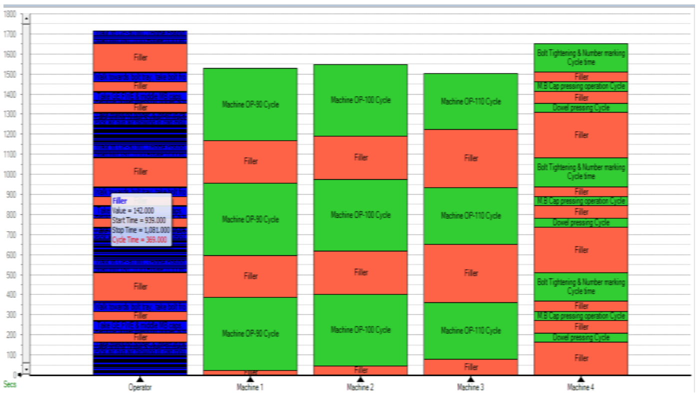

Figure 8: Man-Machine Chart for Cell No.3

Figure 8 represents the man-machine chart of cell 3 of the crankcase line. In this cell 3, the operator operates eight different machines from OP-080 to OP-120. Here it is observed that the Operator in cell 3 has an idle time of 44 to 142 seconds. As this operator is loaded more than 90% but the operator is having idle time more hence it is possible to utilize this operator more.

Figure 9 represents the man-machine chart of cell 4 of the crankcase line. In this cell 4, the operator operates four different machines from OP-130 to OP-160. Here it is observed that the Operator in cell number 4 has an idle time of 56 seconds. As this operator is loaded more than 90% and hence it is not possible to utilize this operator more.

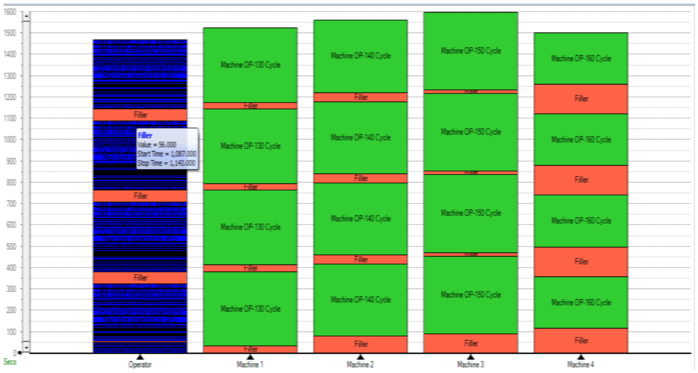

Figure9: Man-Machine Chart for Cell No.4

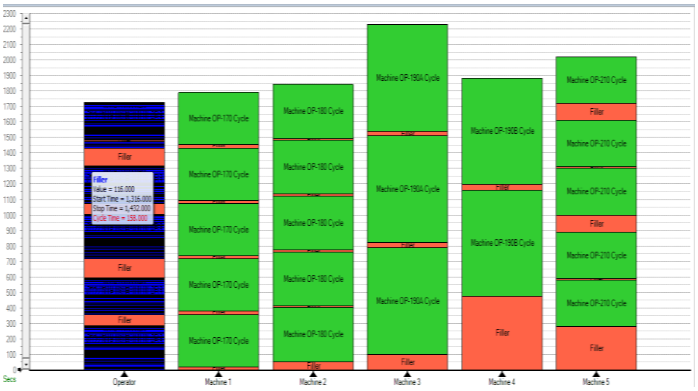

Figure10: Man-Machine Chart for Cell No.5 (OP-190A & 190B)

Figure 10 represents the man-machine chart of cell 5 of the crankcase line. In this cell 5, the operator operates five different machines from OP-170 to OP-210. Here it is observed that the Operator in cell 5 operators machine OP-190A and machine OP-190B alternatively. From the precedence network diagram in figure1, it can be understood that the operator operates OP-170-180-190A-OP-210 and after completion of this cycle he operators as OP-170-180-190B and OP-210. This cycle of operation is alternatively performed. Also from this man-machine chart, this operator has an idle time of 56 seconds. As this operator is loaded more than 83% and hence it is not possible to utilize this operator more.

Figure11: Man-Machine Chart for Cell No.6

Figure 11 represents the man-machine chart of cell 6 of the crankcase line. In this cell 6, the operator operates two different machines from OP-220 and OP-230. Here it is observed that the Operator in cell number 6 has no idle time. As this operator is loaded more than 95% and hence it is not possible to utilize this operator more.

6.2. Operator Utilization Crankcase Production Line

Workstation/ Cell No.	Operation	Total Manual Time seconds	Operator Utilization %
Cell 1	OP-001 To OP-005	342	95
Cell 2	OP-010 To OP-080	335	93
Cell 3	OP-090 To OP-120	341	95
Cell 4	OP-130 To OP-160 (OP-220 Manual Activity)	332	92
Cell 5A/5B	OP-170 To OP-210	285/300	83
Cell 6	OP-220 To OP-235	390	100

Table 3 gives an operation described in the workstation and cell wise operator utilization at each six number of cells of the crankcase production line. This table depicts each operation and the total manual activity time required to finish that particular task in seconds and operator utilization percentage in each cell or workstation. From this table, we can identify that the operator in each cell is more than 85% utilized and hence further loading of operator and reduction of operator (workstation) is not possible. To balance the crankcase production line the manual workload in cell or workstation number six needs to be reduced. Also, the man-machine chart of cell 3 in figure 11 shows that operator 3 is idle for 146 seconds and this idle time of operator needs to be utilized. As it is not possible to distribute the work content to cell 1, 2, 4 because all the remaining operators are more than 90 % to 95% loaded as compared to bottleneck operation cycle time of 360 seconds. Hence further loading of all these operators is not possible.

It can be observed from table 3; the operator in cell 6 is overloaded because the maximum time of 185seconds out of total 199 seconds the operator is taken only for manual air blowing operation of OP-220. If for this operation some automation in air blowing is done so it is possible to reduce the total manual work content in cell 6 and the operator load can be balanced. So accordingly suggestions are given to industry, about this so that it is possible to balance the crankcase line.

6.3. Verification of suggestions for Cell 3

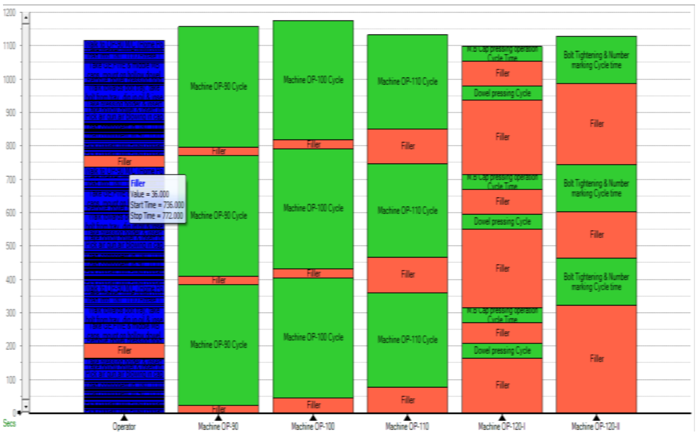

Figure12: Man-Machine Chart for Cell No.3

Also as it has been seen from figure 8, the operator 3 in cell 3 having idle time of 142 seconds which is quite high so to utilize this operator idle time it is possible to keep a buffer at OP-120, so that one extra component will always be placed at OP-120 workstation. This arrangement will greatly reduce the operator idle time from 142 seconds to 36 seconds.

7. CONCLUSIONS

The current industrial line balancing study is carried out for an engine component (Crankcase) production line. From the time study data collected with the help of video-based time study software Timer-pro and the theoretically calculated number of workstations shows that it is not possible to reduce the number of workstations on the production line. The existing Crankcase production line layout consists of six numbers of workstations or cells. At the same time, the Yamazumi chart and Man-machine chart tools in timer-pro software helps to identify operator utilization and operator and machine idle time.

So by utilizing these various tools in video-based time study and line balancing software Timer-pro some important suggestions are given to the industry so that by implementing these suggestions they can improve the operator utilization and overall line balancing of the production line

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