Vol. XII & Issue No.12 December - 2019
INDUSTRIAL ENGINEERING JOURNAL

LINE BALANCING USING GENETIC ALGORITHM FOR THE IMPROVEMENT OF EFFICIENCY

R Naresh Kumar Reddy
Dr. P Venkataramaiah

Abstract

The greentech industries pvt ltd is a large scale automobile ancillary company which manufactures spare parts of different automobiles. In the industry mainly casting and finishing processes are performed. This study is carried on a finishing process line of a part in the industry. The line studied is Suzuki 1.5L housing in greentech industries pvt Ltd. This line contains six semi-automated machines OP10, OP20, OP30, Leak test, Honing and Washing on which three operators are working, handling two machines each. The standardized work combination chart, production capacity sheet and operator load chart are used to determine idle time of the operator, production capacity, load on the operator and line efficiency. The line is keenly studied and is then balanced so that, the load on operators is almost equal, idle time of operators is reduced and the efficiency of the line is increased. The layout is designed based on the allocation of operators to machines. The allocation of operators is made by using genetic algorithm.

Key Words: Line balancing, Idle time, production capacity, Load on the operator, Genetic algorithm, Layout design.

1. INTRODUCTION

Line balancing is one of the major problems the manufacturing industries are dealing from a very long time. A production line is said to be a balanced line when the production of upstream machines is in sync with the production of downstream machines. One way to achieve this is by distributing load almost equally on every machine or operator. This report mainly focuses on this statement. By equally distributing load on the operators the efficiency of the line increases as the idle time of the operators or waiting time of machines are reduced. But in actual production line it is very difficult to distribute equal load on operators as the skills of all the working operators may not be same, hence instead of equal, almost equal distribution of load is used. In this paper the load on the operator refers to the effective working time of the operator. If the operator works for most of the time effectively in his available shift time, then he is taking more load on him and vice versa. The main objective of this paper is to allocate operators to machines in such a way that the load on the operators is almost equal and the operators shall use 70% of the shift time effectively. For this, genetic algorithm is used for the allocation of operators. Initially an allocation is randomly selected which is then crossover and mutated to find the optimal allocation. The optimal allocation gives a balanced line. The objective function is equal load distribution. Rubinovitz and Levitin [1] used genetic algorithm for the assembly line balancing problem and proved that genetic algorithm gives quality solutions than branch and bound algorithm. Kim, Y.J, Kim, Y.K & Cho, Y [2] used genetic algorithm for workload smoothing. In this project the main focus is made on maximization of workload smoothness. By doing this the efficiency of the line is increased. Hsio-Lan Fang [3] used genetic algorithm in timetabling and scheduling of tasks. Matthias Grobner, Peter Wilke [4] optimized the schedules of nurses in a hospital using hybrid genetic algorithm. At present, in the line operator 1 handles OP10 and OP20 machines, operator 2 handles OP30 and leak test machines, and operator 3 handles Honing and Washing machines. The genetic algorithm is used to find whether this allocation is optimal or not, if not, then optimal solution is determined.

2. METHODOLOGY FOR CALCULATING IDLE TIME, PRODUCTION CAPACITY AND LOAD ON OPERATOR

The industry uses three different charts for the calculation of idle time, production capacity and load on the operator. The standardized work combination chart is used for the calculation of idle time. The production capacity and bottle neck are found from production capacity sheet, and Operator load chart is used to calculate the efficiency of the line and load on the operator.

2.1 Standardized Work Combination Chart

The time taken by each operator to perform tasks on a machine allocated to them is noted. By using this data the handling time and idle time of the operator for that particular machine are calculated in standardized work combination chart. Figure 2.1 shows the standardized work combination chart for operator 1 working on OP10 machine.

2.1.1 Handling Time

Handling time is the time taken by the operator for handling a part on that machine. For OP10, Handling time =7+2+10+23+4+3 = 49 sec.

2.1.2 Idle Time

It is the time the operator has to wait after finishing all his activities for the machine to complete its run time. Note that the idle time of operator do not consider the time for unloading the machined part, loading new part and blowing the fixture. This is because only after unloading, blowing and loading the part the machine will start its operation. For OP10, idle time is 130-7-23-4-3=93 sec.

:Customer		Garret	Standardized work combination chart		
:Part Name		Suzuki 1.5L			
:.Part No		806037-0007	OP Descrip-:tion	OP10		
Item .No	Work description		Handling	Machining	Walking
1	Arranging parts		7.0		
2	Unload part in OP 10		2.0		
3	load part in OP 10		10.0		
4	Machining time			130.0	
5	Blowing machined part and Visual Checking		23.0		
6	Measuring with gauges		4.0		
7	Part placed on OP20 Table		3.0		

Figure 2.1 Standardized work combination chart for OP10 machine

Handling time=49 sec Idle time=93 sec

:Customer		Garret	Standardized work combination chart		
:Part Name		Suzuki 1.5L			
:.Part No		806037-0007	OP Descrip-:tion	OP20		
Item .No	Work description			Machining	Walking
1	Arranging parts		6.0		
2	Unload part in OP 20		4.0		
3	Blowing Fixture		15.0		
4	load part in OP 20		9.0		
5	Machining time			145.0	
6	Blowing machined part and Visual Checking		23.0		
7	Measuring with gauges		15.0		
8	Part placed on OP30 Table		3.0		

Figure 2.2 Standardized work combination chart for OP20 machine

Handling time=75 sec Idle time=98 sec

:Customer		Garret	Standardized work combination chart		
:Part Name		Suzuki 1.5L			
:.Part No		806037-0007	OP Descrip-:tion	OP30		
Item .No	Work description			Machining	Walk-ing
1	Unload part in OP 30		5.0		
2	Blowing fixture		12.0		
3	load part in OP 30		42.0		
4	Machining time			502.0	
5	Blowing machined part and Visual Checking		62.0		
6	Measuring with gauges		122.0		
7	Part placed on OP Leak test Table		3.0		

Figure 2.3 Standardized work combination chart for OP30 machine

Handling time=246 sec Idle time=315 sec

:Customer	Garret	Standardized work combination chart			
:Part Name	Suzuki 1.5L				
:.Part No	806037-0007	:OP Description	Leak test		

Item .No	Work description		Machining	Walking
1	Arranging parts	12.0		
2	Unload part in OP leak test	1.0		
3	load part in OP leak test	3.0		
4	Machining time		34.0	
5	Part placed on Honing table	1.0		

Figure 2.4 Standardized work combination chart for Leak test machine

Handling time=17 sec Idle time=21 sec

:Customer	Garret	Standardized work combination chart			
:Part Name	Suzuki 1.5L				
:.Part No	806037-0007	OP Descrip-:tion	Honing		

Item .No	Work description		Machining	Walking
1	Unload part in Honing	25.0		
2	Loading part in OP Honing	26.0		
3	Machining time		391.0	
4	measuring with gauges	73.0		
5	Part placed on Washing table	4.0		

Figure 2.5 Standardized work combination chart for Honing machine

Handling time=128 sec Idle time=314 sec

:Customer	Garret	Standardized work combination chart			
:Part Name	Suzuki 1.5L				
:.Part No	806037-0007	OP Descrip-:tion		Washing	

Item .No	Work description		Machining	Walking
1	Unload part in Washing	32.0		
2	Loading part in OP Washing	36.0		
3	Machining time		61.0	
4	Blowing machined part	60.0		
5	Part placed on trolley	2.0		

Figure 2.6 Standardized work combination chart for Honing machine

Handling time=130 sec Idle time=0 sec

2.2 Production Capacity Sheet

The chart shown in the Figure 2.7 is called as production capacity sheet. It is used to find the output per shift of each machine, bottleneck of the line and production capacity of the line. In standardized work combination chart, the time taken by the operator to change the tool of the machine, quality inspection time and break time is not considered. But in real time production line, there will be breakage of tool and the machine remains idle until the operator changes the tool. Also, the operator has to for every one hour do quality inspection to check the quality of the batch produced in that hour. There will be break time to the operator for 10min in his shift. The frequency in production capacity sheet refers to 'for how many parts'. For example, the frequency in tool change time is for how many parts has the tool failed. The machine which has lowest output is considered as bottleneck. The output capacity of the bottleneck is considered as production capacity of the line. The values of time are taken in the units of per part i.e. time taken per part. This is done by dividing the time with frequency.

Customer:	Garret	Production Capacity Sheet		Production date	Thursday, March 07, 2019	
Part Name:	SUZUKI1.5L			Work Time:	450	minutes/shift
Part No.:	806037-0007	Project Content	SUZUKI 1.5L	Production Capacity	134	pcs/shift ▲

Process No.	Process Name	Equipment No.	Basic Job Time(sec)				Secondary Job Time (Sec)							Production Capacity			
			Manual Time (A)	Essential Manual Time (B)	Machining Time (C)	Finish Time (B+C)	Tool Change Time(D) Time	Tool Change Time(D) Frequency	Quality Inspection(E) Time	Quality Inspection(E) Frequency	Others(F) Time	Others(F) Frequency	Total Time Avg(D,E,F)	Cycle Time	Cycle Output		Output/shift (pcs)
1	OP 10	GMH055	49	12	130	142	58	150	105	24	600	134	9	151	1	178.5	178
2	OP 20	GMH046	75	28	145	173	56	80	105	19	600	134	11	184	1	147.0	147
3	OP 30	GMC100	246	59	502	561	58	100	605	18	600	134	39	600	3	134.9	134 ▲
4	Leaktest	GMJ056	17	4	34	38					600	134	4	42	1	635.6	635
5	Honing	GMC166	128	51	391	442			105	26	600	134	9	451	4	239.7	239
6	Washing		130	68	61	130					600	134	4	134	4	803.1	803

Figure 2.7 Production capacity sheet of Suzuki 1.5L line

2.3 Operator Load Chart

The operator load chart is used to calculate the load on the operator. It is also used in the calculation of efficiency of the production line. The number of operators in the Suzuki1.5L line is three. The load on each of the three operators is calculated using operator load chart. The total time spent on each task by the operator at the machines he is operating is calculated. The percentage load is calculated. The load on the operator is 100% when he utilizes all the available shift time to work on the machine. The shift time is 7.5 hours or converting into minutes it will be 450 minutes. If the operator uses 450 minutes or 27000 sec completely then the load on the operator is 100% which is impossible in reality. Therefore, the load on the operator is the amount of time he fruitfully utilized in the available 27000 sec. The efficiency of the line is calculated. It is defined as the average time all the operators have spent fruitfully in their shift. It is calculated by taking average of all operators load. The line is said to be more efficient if the average load on the operators is more or the line is more efficient if the idle time of the operators is less.

Operator load = (no of times the operator performing a task) *

(Time taken by the operator to perform that task)

For example, operator 1 operates OP10 and OP20 machines. The load on operator to perform the task of arranging parts is = (134*7) + (134*6) = 1742 sec.

The operator has to arrange parts 134 times on each machine (production capacity of line) and time taken on machine OP10 is 7 sec while time taken on OP20 is 6 sec.

As shown in Figure 2.7 the number of parts coming out of OP30 machine in one cycle is 3 and for leak test machine is 1. Also from Figure 3.8 the production capacity of the line is 134 parts. The time taken by operator for each task on machine OP30 is shown in Figure 3.4 and for leak test it is shown in Figure 3.5.

Total time used for arranging parts by operator 2 in entire shift = 12 *134

=1608 sec

As there is no arranging of parts task in OP30 machine only leak test is considered. For arranging a part the time taken is 12 sec, therefore for 134 parts the time taken is 12*134 =1608 sec.

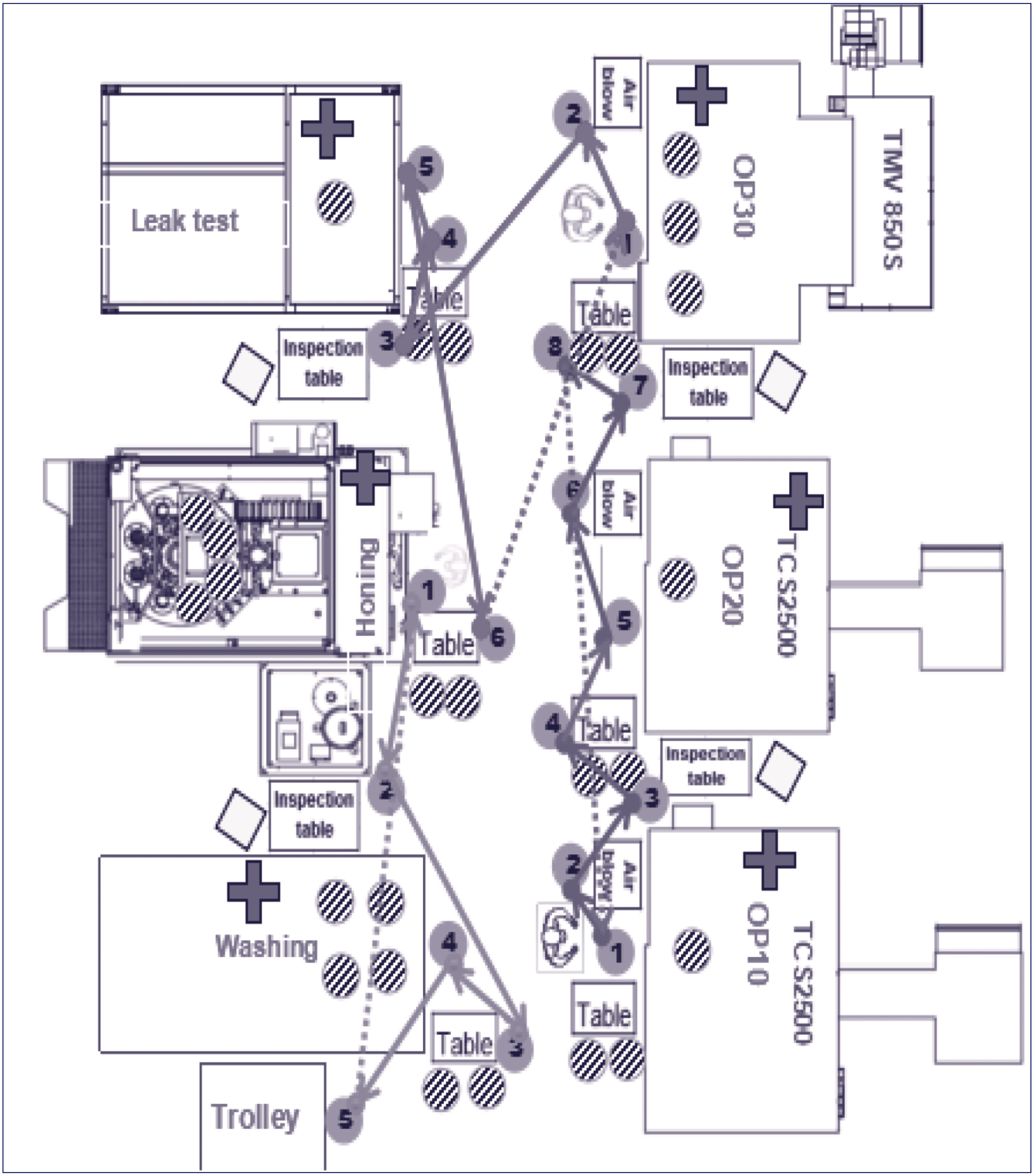


Figure 2.8 Suzuki 1.5L existing layout

Operator Load chart（134pcs/shift）

		Part/Project Na:SUZUKI1.5L			Part No: 806037-0007	
Approved:			Checked:		Prepared:	
Sl. No:	Work Description	OP10&OP20(sec)	OP30&Leaktest(sec)	Honing& WASHING(sec)	Over All Line Operators Avg Load %	
1	Arrange parts	1742	1608			
2	Un load parts	804	359	1938		
3	Cleaning fixture	2010	540			
4	Load the part	2546	2292	2108		
5	Blowing machined	6164	2790	2040		
6	Deburing & filling					
7	Visual checking					
8	Measuring with gages	2546	5490	2482		
9	Part placed on next op	804	269	204		
10	Bolts In		2412			
11	Bolts out					
Total Time(Sec):		16616	15760	8772		13716
Operation Ratio:		61.54%	58.37%	32.49%		50.80%

Figure 2.9 Operator load chart for Suzuki 1.5L

Figure 2.9 shows the Operator load chart for operator 1. From the Figure 2.3, it is evident that the load is not evenly distributed among the operators. This means that the human resources are not effectively used. Operator 3 can be eliminated by distributing his load between operator 1 and 2. This is a case of unbalanced line. Hence there is need for balancing the line. The line is said to be balanced if the load is distributed evenly among all the operators.

3. LINE BALANCING USING GENETIC ALGORITHM

3.1 Assumptions

i. As operator 3 is handling two small machines comparatively to operators 1&2, it is assumed that operator 3 is less skillful than operators 1&2.

ii. As operator 3 less skillful, the time taken by operators 1&2 to perform the tasks that were previously performed by operator 3 is less or equal to time taken to perform similar tasks by operator 3.

iii.To avoid questioning, the time taken by operators 1&2 is considered equal to time taken by operator 3.

iv. The operators 1&2 are equally skillful. The time taken by the operators is same in performing a task on any machine.

3.2 Constraints

As the operators have been handling two machines each earlier, the no of machines to be handled after allocation should be equal to or more than two machines.

Genetic Algorithm

There are five phases in genetic algorithm.

i. Initial population

ii. Fitness function

iii. Selection

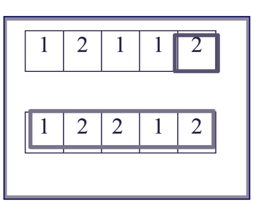
iv. Crossover

v. Mutation

These five phases are briefly explained below.

Initial population

The process begins with a set of individuals called population. Each individual is a solution. An individual is characterized by a set of parameters known as genes. Genes are joined to form a chromosome. Chromosome is the solution required.



Gene, Chromosome, and Population.

Figure 3.1 Example of gene, chromosome, and population

As shown in Figure 3.1, each number individually is called a gene. The collection of genes is chromosome. The set of chromosomes is called as population.

Fitness function

The fitness function determines the fitness of an individual. The chance that an individual will be selected for further reproduction is based on its fitness.

Selection

The idea of selection phase is to select the fittest individuals and make them pass the genes to the next generation. Individuals with high fitness have higher chance of reproduction.

Crossover

Crossover is the most significant phase in genetic algorithm. For each pair of parents to be mated, a crossover point is chosen at random from within the genes.

Mutation

In some newly formed off-springs, some of their genes are subjected to a mutation with low random probability. Mutation means genes changes in the chromosome itself.

3.3 Procedure For Generating Random Numbers

2	1	2	1	1	1
1	1	1	1	2	1
1	2	2	1	1	2
2	2	2	1	1	1
1	1	1	2	1	1
1	2	2	2	1	1
2	2	2	2	2	1
2	1	1	1	1	2
1	2	1	1	1	2
1	2	2	2	1	1
1	2	2	1	1	2
2	1	1	1	2	1
1	2	1	1	2	2
2	2	2	1	2	1
1	2	1	2	2	2
1	1	1	1	2	2
1	1	2	2	2	1
1	1	1	2	2	2
1	1	1	2	1	2
1	1	1	2	1	1

A random population is generated in Excel using formula =RANDBETWEEN (1, 2) in a cell and use fill handle to drag along column to generate random numbers. Some random numbers do not satisfy the constraint such chromosomes are mutated or cross over or eliminated.

3.5 Fitness Criteria

The fitness function is load on the operator. If the load on the operator is almost equally distributed then it is the fittest solution.

Let, i = no of machines operating by operator k

j = no of tasks to be performed on a machine

k = no of operators

N_i = no of times the tasks are performed on machine i

T_{ij} = time taken to complete task j on machine i

L_k = load on operator k, then

When operator k performs j tasks on machine i then load on operator k can be calculated as

$$L_{k=1}^{k} = \sum_{i=1}^{i} \sum_{j=1}^{j} N_i * T_{ij}$$

If L_1, L2.... . . L_k has almost equal values then that solution has high fitness value.

Initially, the load calculations are carried for all the chromosomes in the randomly generated population. Then, the chromosomes with highest fitness value are separated and second iteration is performed for new fitter population. The iterations are continued till an optimal allocation is reached.

OP10	OP20	OP30	LEAK TEST	HONING	WASHING
2	1	2	1	1	2
1	1	1	2	2	2
2	1	2	1	2	1
1	2	1	2	1	1
2	2	1	2	1	1
2	2	2	1	1	1

Figure 3.2 Randomly selected population

In Figure 3.2, six chromosomes are selected to show fitted solutions and unfitted solutions. Each row represents a chromosome. Each cell in a row represent gene (machine). There are 6 chromosomes (allocation) with different genes. The best chromosome is selected by performing cross over and mutation. The best fitted chromosome or solution is that allocation which divides the load evenly among the operators. Each chromosome is considered as an allocation. Observing chromosomes 4, 5 and 6, chromosome 5 is the crossover product of chromosome 4 with chromosome 6 up to gene 2.

1	2	1	2	1	1
2	2	2	1	1	1

Before crossover

2	2	1	2	1	1

1	2	2	1	1	1

After crossover

By observing chromosomes 1, 2 and 3 showed in Figure 3.2, it is clearly evident that chromosome 1 is the rotational crossover of chromosome 2 up to gene 2 with chromosome 3.

1	1	1	2	2	2
2	2	1	1	1	2

Two times rotation of chromosome 2

2	2	1	1	1	2
2	1	2	1	2	1

Crossover of rotated chromosome 2 with chromosome 3 at gene 3

2	1	2	1	1	2

2	2	1	1	2	1

In this way, crossover and mutation are performed and optimal allocation is founded.

3.6 Best Fitted Solution

The allocations shown below gave optimal results for the line.

1	1	2	1	2	2

2	2	1	2	1	1

Both can be used as solutions but, as the operator 1 is more experienced in operating machines OP10 and OP20 while operator 2 is experienced in operating machine OP30, chromosome 1 is selected as best fitted solution.

Operator Load chart（134pcs/shift）				
		Part/Project Na:SUZUKI1.5L		Part No: 806037-0007
Approved:		Checked:		Prepared:
Sl. No:	Work Description	OP10,OP20 and Leaktest(sec)	OP30,Honing& Washing(sec)	Over All Line Operators Avg Load %
1	Arrange parts	3350		
2	Un load parts	938	2163	
3	Cleaning fixture	2010	540	
4	Load the part	2948	3998	
5	Blowing machined	6164	4830	
6	Deburing & filling			
7	Visual checking			
8	Measuring with gages	2546	7972	
9	Part placed on next op	938	339	
10	Bolts In	2412		
11	Bolts out			
Total Time(Sec):		21306	19842	20574
Operation Ratio:		78.91%	73.49%	76.20%

Figure 3.3 Operator load chart for optimal allocation

From Figure 3.3, the load on operator 1 is 78.91 and operator 2 is 73.4% which is closest to our optimal criteria satisfying constraints hence it is considered as the optimal allocation for the line.

4. DESIGN OF LAYOUT

The existing line is studied and operators are reduced by one number. The remaining operators are then allocated optimally using genetic algorithm in such a way that the line is balanced. The layout is modified according to the new allocation. According to the new allocation, each operator has to handle three machines. The new proposed layout is shown in Figure 4.1.

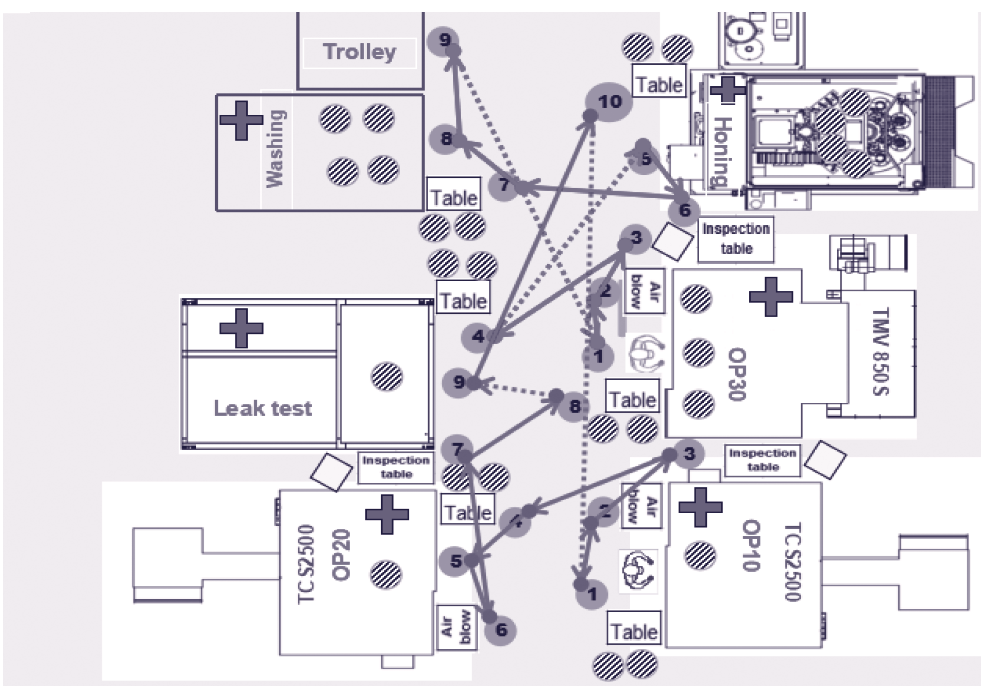
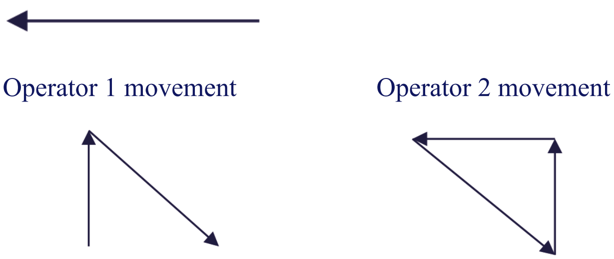


Figure 4.1 Suzuki 1.5L new proposed layout

According to the new allocation operator 1 should handle OP10, OP20 and leak test machines. Hence the layout is designed in such a way that the distance travelled by the operator should be minimum. Similarly, operator 2 should handle remaining machines. Hence the machines operated by operator 1 are placed closely together. Likewise, the machines operated by operator 2 are placed closely. The layout is designed in such a way that the operators move in triangular pattern as shown below. This pattern helps the operator to move without difficulties across the machines.



5. RESULTS

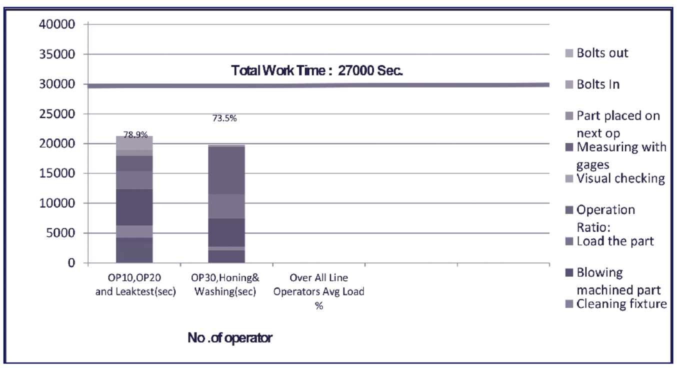


Figure 5.1 Graphical representation of operator load of optimal allocation

From Figure 2.9 the efficiency of the line before balancing is 50.8% with three operators working in the line. For the same production capacity of the line one operator is eliminated. Therefore, the efficiency of the line is increased. From Figure 3.3 the efficiency after removing the operator becomes 76.20%. Hence the efficiency of the line increased by 25.40%. From Figure 2.9 the load on the operators before balancing is 61.54%, 58.37% and 32.49% respectively for operators 1, 2and 3. After balancing the line through allocation of operators using genetic algorithm, the load on the operators is 78.91% and 73.49% respectively as shown in Figure 3.3. As there is no much difference in the load of operators the line is said to be balanced. The layout of the line is changed according to the new allocation. The layout is designed such that the distance travelled by operators between the machines is minimum. Also the movement of operators across the machines is made easy. The layout is changed such that the machines operated by one operator are placed closely also the movement of operators follow a triangular cyclic pattern so that there is no or less difficulty in movement of operators.

6. CONCLUSION

As the operators are continuously performing same tasks, eventually the time to perform the tasks decreases, there by changing the idle time of operator, production capacity and efficiency. In line balancing the solution cannot be a fixed one. There will be continuous improvement in the line hence the line shall be studied and balanced from time to time. Generally, in genetic algorithm the input data have a range of values of which best suitable solution is found based on the value of fitness function. On the contrary, in this project the fitness function have a range of values i.e. the load distributed among operators is even. The assumptions made to simplify this problem may not possible in real, hence the results may vary. This report serves as an example for using genetic algorithm in non-traditional way to find optimal solutions for different problems. This method gives best results when the production line contains machines in large number. Generally, rabbit chase a lean manufacturing technique is used when two operators work in a U-shaped line but in this paper a triangular cyclic movement of operator between the machines is used. As the pace of working of operators is almost equal, the distance moved by the operators can be reduced if the number of machines he has to operate is constrained.

REFERENCES

[1] Rubinovitz, J., Levitin, G., & Shnits 'A genetic algorithm for robot assembly line balancing' European Journal of Operational Research 168(3), 811-825 (2006).

[2] Kim, Y.K., Kim, Y.K.,& Cho,Y. ' A heuristic based Genetic algorithm for workload soothing in assembly lines' Computers & Operations Research, 25(2),99-111 (1998).

[3] Hsiao-Lan Fang 'Genetic Algorithms in Timetabling and Scheduling' Ph.D. thesis, Department of Artificial Intelligence, University of Edinburgh, (1994).

[4] M.Grobner, P. Wilke 'Optimizing Employee Schedules by a Hybrid Genetic Algorithm' pp.463472, Springer-Verlag (2001).

[5] C Merengo, F Nava, A Pozzetti 'Balancing and sequencing manual mixed-model assembly lines' International Journal of Production Research 37 (12) pp. 2835-2860. (1999).

AUTHORS

Dr. P Venkataramaiah, Professor, Industrial Engineering Dept., Sri Venkateswara University, College of Engineering, Tirupathi – 517 502

R. Naresh Kumar Reddy, Student, Industrial Engineering Dept., Sri Venkateswara University, College of Engineering, Tirupathi – 517 502
Email: nareshkumarreddy007@gmail.com