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ABSTRACT:

Line balancing addresses the issues of balancing production, and it generally minimizes the idle time for all the events and combinations of workstations. Factors such as lack of materials, design changes in the product, and labor position may also be considered in line balancing. We approached a bearing manufacturing industry in Coimbatore, India, and proposed a solution in increasing the production of bearing by the method of line balancing. In this paper, we discuss solving the line balancing problem in two different platforms; the first, by rearranging the existing tasks over the workstations, and the second, by using Timer Pro Professional software when grouping similar kinds of activities to find out the most optimized productivity. The results obtained were optimistic and profitable to the company. We were able to increase production of bearings by 4628 bearings by rearranging, and 55,770 bearings by using the Timer Pro Professional software. This proposal suggests the company should change its present line of operations for better productivity and profitability.

Keywords: Line balancing; Productivity; Timer Pro Professional; Production.

THE line balancing problem is one of the most important problems of the preliminary design stage for flow line production systems. Line balancing can be defined as a concept of reducing the imbalance between the workers and the workload to achieve desired production rates. This article is based on a project proposal submitted for balancing a company's production line. It focuses on a solution for a production line with a relatively simple structure. For a given set of operations, the classical line balancing problem consists of assigning each operation to a workstation to minimize the number of workstations and satisfy precedence constraints. The balance delay time will be minimal if and only if the numbers of workstations are minimal too. The dual problem is minimization of the cycle time for the given number of workstations. The experiment was conducted at Bimetal Bearings Limited in Coimbatore, India, which has a strong manufacturing base in bi-metallic bearings backed by testing and R&D facilities.

Preferably, industries should implement lean manufacturing to eliminate all kinds of unwanted elements that would proliferate the productivity of the line. The arrangement of machine capacity must be relatively secure for uniform flow of manufacturing. If the demand for the product changes, any change in line balancing should not have any negative effect on productivity. Here is an example of such optimized results by Agnetis (1997), which increased production rates from 1100 units to 1800 units per day and showed that increasing the number of AGVs and processors can enhance the production rate at each stage of production.

There are three possibilities of line balancing. The first possibility focuses on implementing the most effective direction, at least as far as balancing the line is concerned, to increase the output. The second possibility is to locate another product close to the original product, so that some idle machines may be used jointly. The third possibility is to estimate the output of the last workstation, which can serve as an estimate of the minimum output of all the immediate workstations. The following goals have primarily been considered in this article's line balancing concept:

- The objective is to apply this line balancing concept to reduce wait time on the component and machine for improving the production rate. The parameters, including cycle time, line efficiency, and balanced delay, are optimized to obtain balance.
- The other objective is to obtain perfect balance in the line of bearing production, both by rearranging the line of processes as well as to suggest a solution from a time study software to create a more productive environment.

Literature Review

Line balancing is one of the basic principles in improving productivity, and it is considered a basic tool towards lean manufacturing. Chen et al. (2012) defines line balancing as the problem of assigning various tasks to workstations, while optimizing one or more objectives without violating any restrictions imposed on the line. Chen et al. (2012) has developed the grouping genetic algorithm (GGA) technique to single model balance line for a sewing division similar to what we have worked. Dolgui and Proth (2013) and Boysen et al. (2007) have classified various line balancing methods, classifying them into two basic problems: SALB-1 and SALB-2, with SALB standing for Simple Assembly Line Balancing. SALB-1 typically minimizes the number of workstations for a given cycle time, and SALB-2 minimizes the takt time for a given number of workstations. Our work follows the SALB-2 type problem. Chen et al. (2012) classifies the third type problem as ALBP-3, which maximizes the workload smoothness for a given number of workstations. Many researchers have designed algorithms (Chen et al., 2012; Dolgui & Proth, 2013; Scholl & Becker, 2006), experiments (Chen et al., 2012), and various mathematical or computational methods (Dolgui & Proth, 2013; Scholl & Becker, 2006) to develop proper and optimistic solutions in the industrial arena. We have used a time and motion study software called Timer Pro Professional to achieve optimistic solutions. Reddy (2016) has experimented with the line balancing concept using a time and motion study as well. A time and motion study is the basic tool necessary to optimize machines, workstations, and the complete assembly line.

Existing System – Before Rearranging

For balancing the conventional line, important data such as production volume of all assembly lines, plant layout, operations in sequence, production rate per hour, and takt time for operations are collected and analyzed. Only a conventional production line can be balanced because all the other lines are fully automated and cannot be balanced in the conventional way. This section considers the data in the conventional line of production. In the present assembly line, the production of bearings is already productive and optimistic, but this study aims for much better results. To prepare a balanced assembly line, it is necessary to collect certain data from various sources, including production volume, list of operations in sequence, and time duration required for each operation. Product layout requires line balancing; if any production line is unbalanced, then machinery utilization may be ineffective (i.e., the machine in line may operate only for half of the time). A balanced layout eliminates bottleneck operations and prevents the unnecessary duplication of equipment capacity. Line balancing is a major consideration in layout because imbalance can easily hinder the production. For balancing, it is not essential that the output of the quicker machine should be multiple of the output of the remaining other machines.

Production Requirement

There are a total of five production lines: transfer lines 1, 2, and 3, a conventional line, and a safety stock line; respectively, the production requirement for each is 420,260; 378,600; 418,987; 221,520; and 36,950; with a total production requirement of 1,473,617 bearings per month. This article only considers the conventional line of 221,520 bearings per month, since the other assembly lines are automated.

Table 1. Production requirement of all five assembly lines

Production Line	Transfer line 1	Transfer line 1	Transfer line 1	Conventional line	Safety stock line
Production requirement	420,260	378,600	418,987	221,520	36,950

Present List of Operations in Sequence

The sequence of operations plays a key role in the production process. The following process described below is continuous:

Figure 1. Line of operations in conventional assembly line

- Blanking
- Forming
- Facing
- Chamfering
- Notching
- Piercing
- Oil grooving
- Reaming
- Parting line shaving
- Crush height measuring
- Boring

Takt Time Calculation for Total Production

The takt time is calculated by dividing the available working time per shift (in seconds) by the customer demand rate per shift (in units).

takt time = available work time/day / customer demand/day

= 1 sec per bearing

Refer to Appendix 2 for the calculations. The takt time taken for the production of a single bearing is around one second (1 sec) (refer too Appendix A2). Phrased another way, a bearing is produced or manufactured every single second.

Takt Time Calculation for Conventional Line

The takt time was calculated for total production, which means that it includes all the production lines as discussed earlier. We will calculate takt time for the conventional line only as our line balancing concept applies to the line; we cannot apply balancing for automated lines.

takt time of the conventional line = 6.61 sec per bearing

In a conventional line, the takt time taken for a single bearing is approximately 6.61 sec, which means that production in a conventional line lags behind the total production by 5.51 sec (see Appendix A3) to produce a single bearing. If this line is balanced correctly, it will either increase the company's profit or reduce the cost price of the bearings, which ultimately benefits the company and the market.

Idle Time Calculations

From the cycle time of various operations, the corresponding idle times are calculated and listed below. It is important to emphasize that the data below was recorded before balancing the production line.

Table 2. Calculations and production rate for the conventional line

S. No.	Operation	No. of parts/hours	Cycle Time (in sec)	Idle Time (in sec)
1	Blanking	3580	1.0	0.0
2	Forming	3580	1.0	0.6
3	Facing	2250	1.6	1.0
4	Chamfering	1405	2.6	0.0
5	Notching	1380	2.6	0.6
6	Piercing	1090	3.2	0.5
7	Oil Grooving	975	3.7	1.5
8	Reaming	700	5.2	1.8
9	Parting Line SHAVING	1060	3.4	1.2
10	Crush Height Measuring	1635	2.2	1.3
11	Boring	1060	3.5	0.0
	Total	–	**30.0**	**8.5**

Production Data for the Existing Assembly Line

We have compiled the entire data of the existing assembly line. At the end of this investigation, we will compare the results of the existing line with that of results from rearranged and software methods. It is noticeable that the actual production of the existing line does not satisfy the demand production and that the difference is much too large, which shows a desperate need for line balancing.

No. of workstations = 11
No. of operators = 13
Total cycle time for a bearing = 30 sec
Idle time for a bearing = 8.5 sec
Production time for a bearing = 8.95 sec
Demand / Requirement per day = 8204 bearings
Production per day = 6061 bearings

Proposed Methods and Analysis

Balancing Assembly Line – Rearranging Operational Sequence

The data collected are studied and a new operational sequence is developed to increase the net productivity. The idle time and cycle time for each operation after changing the sequence are tabulated below. Process flow after changing the sequence of operation is as follows. It is very important to note that we have interchanged the position of boring and crush height measuring processes. Let us see how effective this line of balancing is in terms of productivity.

Figure 2. Rearranging line of operation

- Blanking
- Forming
- Facing
- Chamfering
- Notching
- Piercing
- Oil grooving
- Reaming
- Parting line shaving
- Boring
- Crush height measuring

Table 3. Idle time and cycle time after rearranging

S. No.	Operation	Cycle Time (in sec)	Idle Time (in sec)
1	Blanking	1.0	0.0
2	Forming	1.0	0.6
3	Facing	1.6	1.0
4	Chamfering	2.6	0.0
5	Notching	2.6	0.6
6	Piercing	3.2	0.5
7	Oil Grooving	3.7	1.5
8	Reaming	5.2	0.0
9	Parting Line SHAVING	3.4	1.8
10	Boring	3.5	0.1
11	Crush Height Measuring	2.2	1.3
	Total	**30.0**	**7.4**

We have rearranged the existing line of operations, and it is noticeable that there is a change in idle time after restructuring/rearranging the line of operations in the assembly line. There is a reduction in idle time of the line of operations, which is what we have explained as SALB-2. We were able to reduce the idle time from 8.5 sec to 7.4 sec to manufacture a bearing from the restructured line of operations. It is important to note the effectiveness of reduction of idle time. The number of bearings produced after rearranging is 6239 bearings, which is 178 more bearings than that of the existing operational system. Also noticeable is an increase of 55,536 bearings per annum. For the calculations, refer to Appendix A.5.

Timer Pro Professional – Line Balancing Software

Simulation software helps to guide industries to study the situation without taking any risk in the effect of changes. It is also the best tool to analyze and optimize the layout design to derive better productivity, and it also gives an idea of efficiency of the current layout compared with that of simulated layouts. Timer Pro Professional is a simulation software to perform time and motion study to enhance the productivity by identifying optimized and cost reducing improvements. It is the one process analysis tool that those involved in lean operations, workflow analysis, line balancing, and six sigma initiatives cannot afford to be without. The unique balance chart interface from Timer Pro Professional allows users to quickly develop best practices and methods, to identify cost reduction opportunities and quantify savings.

Grouped operational sequence. One of the capabilities of the software is that it identifies and groups similar kinds of operations, thus reducing the idle time of machines more effectively than idea proposed earlier of rearranging the line of operations. Process flow after grouping according to similar operations is as follows:

Figure 3. Sequence of operations obtained from Timer Pro Professional

- Blanking, forming, blanking, and facing
- Notching and piercing
- Oil grooving
- Reaming
- Parting line shaving
- Boring and crush height measuring

Timer Pro simulation results.

We have obtained the most optimized and productive results from Timer Pro software, which is much more effective than the existing and the re-arranged sequences of operations. Pictorial results from the software have also been shown to represent a clear idea of how the optimization has been enacted. The results are as follows.

Optimal number of operators = 11
Takt time = 5.2 sec
No. of workstations = 6
No. of operators = 6
Cycle time = 30 secs
Production per day = 8206 bearings

From the software, we can see that grouping similar operations has reduced the takt time from 8.5 sec to 5.2 sec, which increases the production of bearings from 6061 to 8206 per month, and which undoubtedly satisfies the requirement per month. Hence, grouping increases the productivity of the bearing with a reduced number of workstations and operators, which ultimately increases the company's profit. For calculations, refer to Appendix A6. Optimization from the software has reduced the number of workstations and operators to reduce the takt time, which was the key to tremendous increase in production count. From the software's analysis, the company desperately needs to change its present line of operational sequence for better profitability and market contribution.

Output of the simulation results are shown in Figures 4 through 9. Grouping of workstations can be seen in Figure 4, where 11 operations were grouped into a total of 6 groups, unlike that in the previous two methods, where the processes were machined individually. Because of the grouping of operations, we can reduce the wait time and travelling time from one station to the other.

It is sensible to group various processes that have a lower utilization to one another to ease the assembly line. Cycle time of each grouped process are explained through a bar graph in Figure 5. Actual utilization of operators is shown in Figure 6 for the existing operational sequence without any rearranging or simulation. Compare the value with that of in Figures 7, 8, and 9.

In the existing system, there are 11 workstations, which are not grouped together, and each of which take care of single processes. The utilization of operators and workstations are also less effective. The software groups the operations that can be utilized to a maximum advantage. We can see the optimized output according to individual parameters such as number of operators, production, and takt time, where the value changes according to the optimized parameters. One advantage of the simulation is that we can obtain optimistic values based on our priorities. For example, if takt time is the priority, then we can obtain the estimated optimistic production rate based on optimistic takt time, and the same holds true for other parameters.

Figure 4. Computer-simulated grouping of workstations

Figure 5. Work balance for proposed sequence

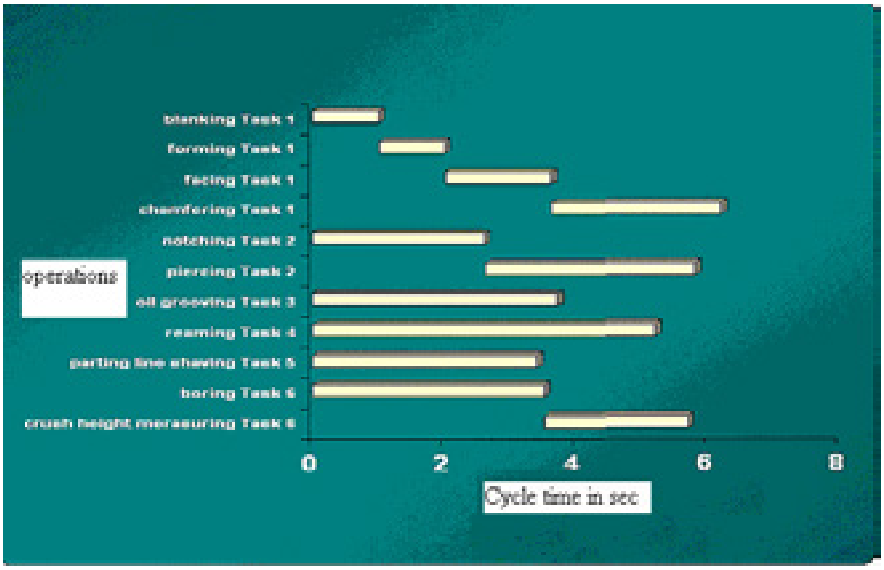


Figure 6. Actual utilization of operators

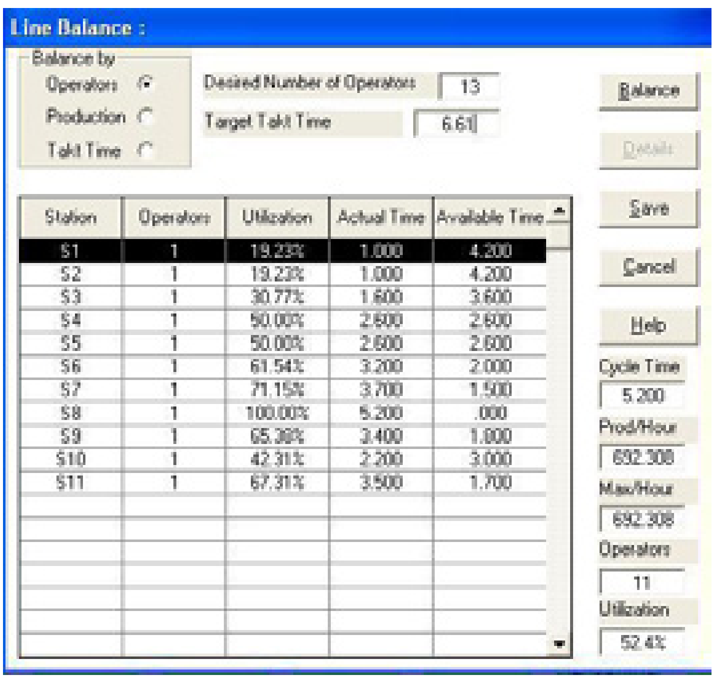


Figure 7. Optimized number of operators

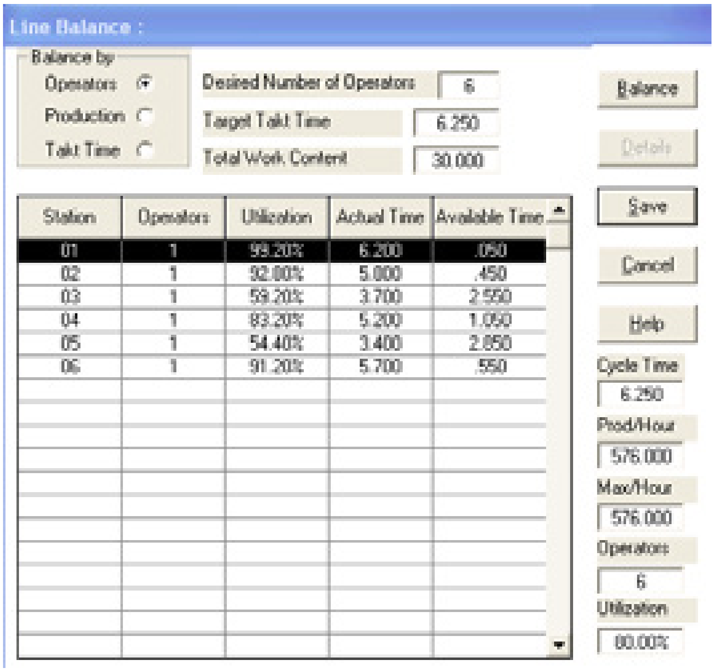


Figure 8. Optimized takt time

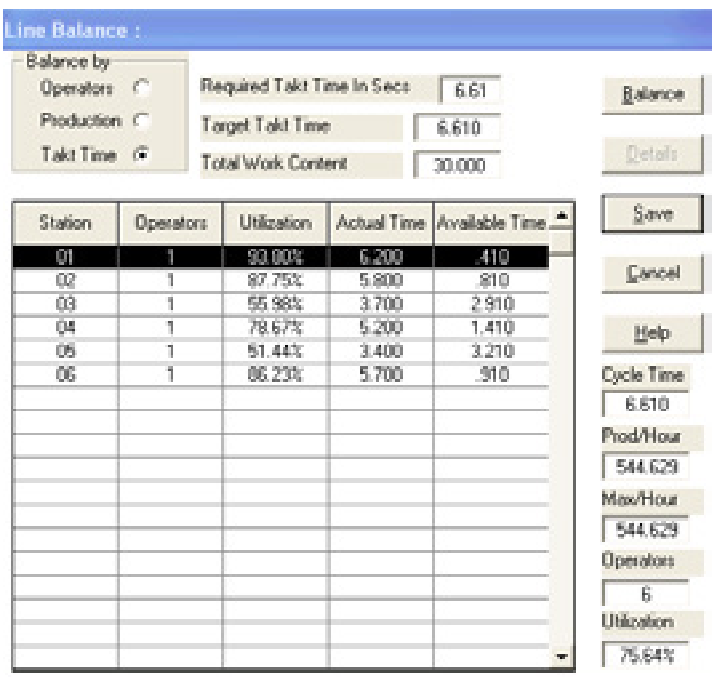
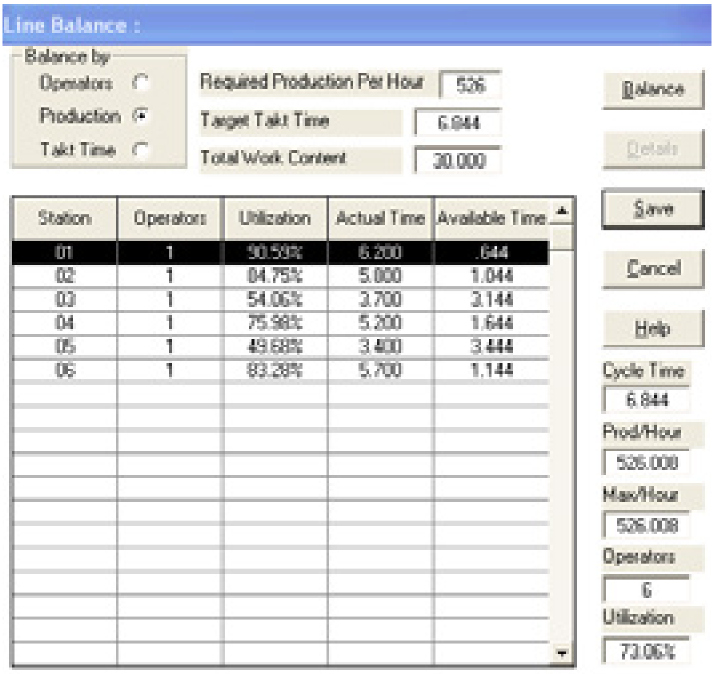


Figure 9. Optimized production rate per hour

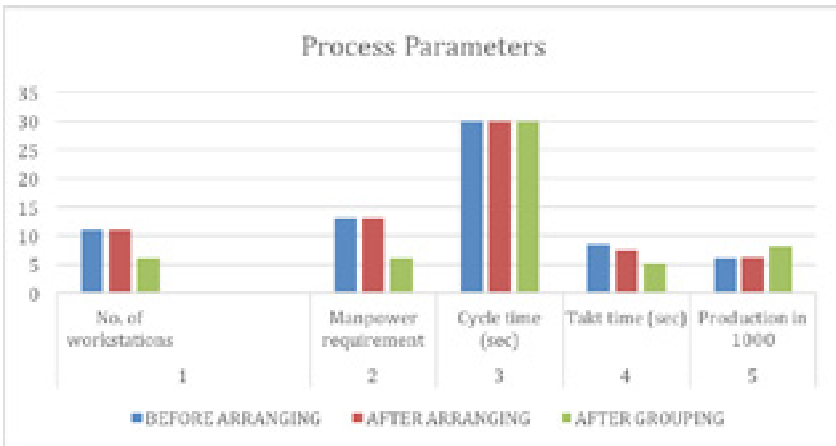


Results and Discussion

The cycle time and takt time for every operation is calculated for all three methods. By grouping the workstation, performing more than one operation in a single workstation, cycle time of the product is reduced. Grouping is done based on cycle time and utilization of machines. The number of workstations is reduced, hence the number of operators required is also reduced. From the optimized results, we can analyze that the higher the utilization of operators and workstations, the higher the productivity. In this article, we can observe that the utilization of work from the workstations has been increased. The second method, in which we rearranged effectively at the last of the operational sequence, made a slight increase in the production volume. In comparison, the results from Timer Pro Professional suggest very effective utilization of work that would substantially increase production. The process parameters are compared in Table 4 and Figure 10. The results after rearranging and after grouping have been tabulated with that of the existing sequence below.

Table 4. Comparison of the results of the three methods

S. No.	Consideration	Before Arranging	After Arranging	After Grouping
1	No. of workstations	11	11	6
2	Manpower requirement	13	13	6
3	Cycle time (in sec)	30.00	30.00	30.00
4	Takt time (in sec)	8.5	7.4	6.61
5	Production of bearings	6061	6239	8206



Conclusion

The data for the time and motion study, including cycle time, production commitment, and production requirement, were collected from the company. After restructuring the process flow, we could observe appreciable increase in production. Using Timer Pro Professional software, the line balancing was carried out and the optimized number of workstations and operators were obtained based on takt time and production requirement, which gave the most optimized results. Timer Pro Professional optimized the line efficiency and workstation utilization, which led to the suggested grouping of workstations to implement pragmatically to proliferate the production volume. A simulated result does not exactly replicate in a practical situation, but it approximately indicates an optimum value that the manufacturing company should consider for productivity. A suggestion was given to the industry about our work both by rearranging the production operation and by using Timer Pro Professional software to increase the assembly line efficiency, which is practically implementable to make the company's product cost effective and competitive in the market.

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Appendix A

A1. Basic Formulas for Calculations

Takt time is calculated by dividing the available working time pershift (in sec) by customer demand rate per shift (in units).

Takt time = Available work time/day / Customer demand/day

A2. Takt Time Calculation for Total Production

Required no. of bearings per month = 14,73,617
No. of working days = 27 days
No. of bearings per day = 56,667 bearings
Number of shifts = 3 shifts per day
Total Time for single shift = 7.1 hours
For 3 shifts = 1275 min per day
Setup change = 60 min per shift
Net available time = 1275 - (3* time for set up change)
= 1095 min for 3 shifts
Taking efficiency of work = 90%
=1095 * 0.9
= 986 min per day
= 5.475 hour / shift
Takt time for 56,667 bearings = Net Available Time/Demand
= 986/56,667
= 0.017 min / bearing
= 1.02 sec/ bearing

A3. Takt Time Calculation for Conventional Line

Required number for the specific month = 2,21,520 bearings
No. of working days = 27 days
Number of bearings per day = 8204 bearings per day
Number of shifts = 3 shifts
Total time in one shift = 7.1 hours
For 3 shifts = 21.3 hours
=1275 min
Setup change = 90 min
Net available time = 1275 - (3*90)
= 1005 min for 3 shifts
Taking efficiency = 90%
= 1005*0.90
= 904 min for 3 shifts
= 5.025 hour per shift
Takt time for 8204 bearings = Net Available Time / Demand
= 0.11min / bearing
= 6.61 sec / bearing

A4. Bearing Production for the Existing Line

A4.1. Requirement/Demand for the conventional line

Requirement for the month = 2,21,520 bearings
No. of working days = 27
No. of bearings per day = 8204 bearings

A4.2. Production rate in conventional line

Total number of bearings produced per day = 6061
Total cycle time = 30 sec
Idle time for a bearing = 8.5 sec
Total cycle time including Idle time = 38.5 sec

A4.3. Production time in conventional line

Production time for 6061 bearings = Net Available Time / Production
= 904 / 6061
= 0.149 min / bearing
Production time for one bearing = 8.95 sec / bearing

A4.4. Existing requirements for conventional line

No. of workstations = 11
No. of operators = 13
Cycle time = 30 seconds
Idle time = 8.5 seconds
Production per day = 6061 bearings

A5. Production After Rearranging

Total number of bearings produced per day =6061
Idle time reduced for a bearing = 1.1 sec
No of bearings produced after rescheduling = (38.5/37.4) * 6061
= 6239 bearings
Increase in production = 6239 – 6061
Total number of bearings increased per month = 178 * 26
= 4628 bearings
Total number of bearings increased per annum = 4628 * 12
= 55,536 bearings

A6. Bearing Production After Grouping Sequence

No. of bearings produced after grouping = 526 per hour
Increase in production = 8206 – 6061
= 2145 bearings / day
Total number of bearings increased/month = 2145 * 26
= 55,770 bearings
Total number of bearings increased / annum = 55,770* 12
= 6,69,240 bearings
No. of workstations = 6
No. of operators = 6
Cycle time = 30.0 sec
Production per day = 8,206 bearing