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OPTIMIZING MANPOWER UTILIZATION IN THE MACHINING LINE OF AN AUTOMOTIVE PARTS MANUFACTURING COMPANY

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Highlights:

- Sustainable improvement can be achieved through practical and data-driven application of industrial engineering tools.
- Uneven workload distribution, inefficiencies, and idle time occur due to a combination of process-related and human factors issues, unrealized variation, and poor workflow design in our system. With the use of the right tools and measurement, these can be reduced or eliminated, resulting in a more balanced and effective production system.
- The allocation of processes across workstations greatly affects the manpower utilization. Additionally, various factors, such as travel time, can impact cycle time, further affecting overall efficiency.

Abstract:

Optimizing manpower utilization is crucial for enhancing efficiency and productivity in a labor-intensive manufacturing setting. A machining line in an automotive parts manufacturing company demonstrated high dependency on labor, with minimal automation in place. Additionally, workload imbalances were observed, where some workers handled multiple machines while others managed fewer tasks. These inefficiencies resulted in delays, inconsistent cycle times, and lower productivity. With this, this study aims to focus on the optimization of manpower utilization in the machining line. Time and motion study and line balancing were performed to validate the cycle time for each workstation, examine workload distribution, and calculate the required number of workstations. The results revealed inefficiencies due to variable worker pacing, unoptimized travel, and lack of proper workload distribution that impede overall production flows and increase processing time variations. Based on the analysis, it was determined that the workstations and workers can be reduced from 3 to 2. A set of possible alternatives were drawn to find the most optimal man-to-machine allocation with 2 workers and 7 machines. The alternative with the most balanced workload distribution, minimized worker idle time, and enhanced manpower utilization was recommended for the machining line. The study highlights the importance of data-driven optimization and use of industrial engineering tools in achieving sustainable improvement.

Keywords: optimization, manpower utilization, automotive parts, manufacturing, line balancing, time and motion study.

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1. Introduction

The Philippines was a pioneering leader in automobile assembly in Southeast Asia during 1973, after the launching of the Progressive Car Manufacturing Program (PCMP) with the goal of manufacturing cars under the "Made in the Philippines" trademark. However, in a bid to protect local competitors, import quotas and high tariffs caused a decline in production. The government continues to be keen on developing its automotive industry and attracting new companies to set up assembly plants, even after a number of decades have passed. Output has been limited to the assembly of imported-based vehicles because of the excessive cost of production. Although there were highly robust sales numbers following a pandemic setback, the Philippines' 2023 vehicle production was one of the lowest in Southeast Asia. Programs exist in the meantime to meet the increasing demand for electric vehicles (Statista, 2024).

ABC Company is an automotive parts and components manufacturing company in Calamba, Laguna, Philippines. The company manufactures and assembles automotive parts and transmission and engine assemblies of vehicles

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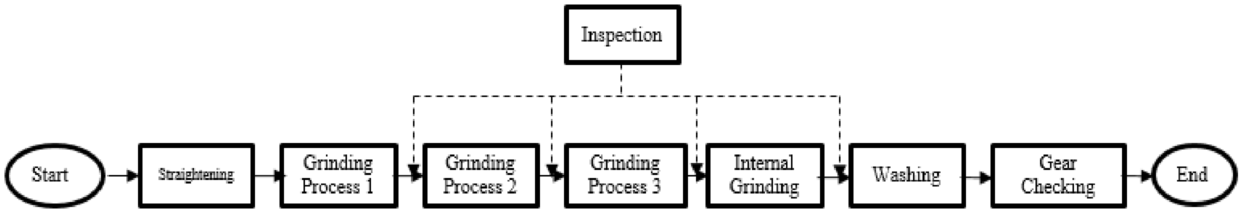

Figure 1: Manufacturing Process Flow of Output Shaft.

such as pickup trucks, mid-size Sports Utility Vehicles (SUVs), Multi-Purpose Vehicles (MPVs), Asian Utility Vehicles (AUV), and high-performance sports sedans. The company's production department is composed of an engine assembly line, transmission assembly lines, and machining lines. The engine assembly line assembles diesel engines, while the transmission assembly lines assemble 6-speed 2-wheel drive (WD)/4-wheel drive (WD) and 5-speed 2-wheel drive (WD) transmission assemblies, respectively. The machining lines involve the manufacturing of automotive components such as gears, sleeves and hubs, and shaft gears.

ABC Company has a machining line that manufactures output shafts. The output shaft is an automotive part that transmits rotational force or power from the engine to other parts of the vehicle (Sirisha, 2023). An external supplier forges the workpieces of the shaft, which then pass through an internal machining process. The machining line of ABC Company is a U-shaped production line. As shown in Figure 1, its internal machining process starts with a straightening process where a metal workpiece called a rough form is cut and then finished part by part in three grinding machines. Each grinding machine processes specific parts of the shaft, ensuring precise shaping according to specifications. After grinding, the rough form is loaded to the internal grinding machine. Internal grinding is used to grind the inner diameter of the workpiece. The shaft then undergoes washing to remove impurities. Finally, the shaft proceeds to the gear-checking machine for the precise measurements of the gear. Three operators and a line leader make up the machining line. Additionally, it has a supervisor who keeps an eye on the other lines nearby. Two to three machines are being run concurrently by the three personnel. As shown in Figure 2, each worker has a designated station with assigned machines. Station 1 operates the machine for

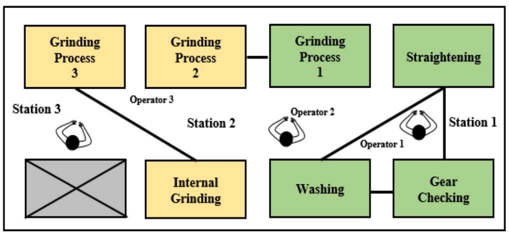

Figure 2: Current manpower assignment in output shaft Machining line.

straightening, washing, and gear checking. Station 2 has grinding processes 1 and 2, while station 3 has grinding 3 and internal grinding.

A tour of the production line reveals that all processes are labor-dependent, as there is no fully automated machine in the line. All processes require a worker to be present for each shaft to be processed. For instance, in the straightening process, the worker places the shaft in the machine, presses the start button, and waits for the machine to perform its operation. Once the machine stops, the worker unloads the shaft and carries it to the next process. In this setup, processing time varies due to the worker's pace in loading, unloading, and transporting the unit. An alert and refreshed worker can operate more efficiently than an exhausted one, as physical fatigue significantly impacts efficiency and effectiveness (Rosselli et al., 2024).

In the line, there are eight machines (1 machine per process), but only seven machines work in the processing of a shaft. The workload distribution is uneven, as one worker handles three (3) machines and the other two handle two (2) machines each. Some processes also require inspection, which increases processing time. This presents challenges, as when a single station's workload consistently increases in comparison to other stations, it eventually becomes the bottleneck and leads to inefficiency (Boysen et al., 2021). Additionally, the distances each worker travels vary, which may affect efficiency (Kumar et al., 2023). These occurrences may entail inefficiencies and opportunity losses for the company. In summary, the following issues were determined:

- Labor-dependent processes
- Uneven workload distribution.
- Idle times experienced by the worker in daily operations

With this, the researchers aim to assess the production line and gather data to be analyzed and develop an optimal solution that addresses the above-mentioned challenges in the machining line.

1.1. General objective

The primary objective of this study is to optimize the manpower utilization in the machining line of ABC Company.

1.2. Specific objectives

In support to the general objective, the specific objectives would be:

- To validate the cycle time of each process in the production line.
- To determine the man and machine utilization ratio.
- To analyze the workload distribution in the production line.
- To propose and evaluate alternatives to find the most optimal solution.

2. Methodology

As illustrated in Figure 3, this study employed an applied quantitative research approach using (3) industrial engineering techniques, including time and motion study, man-machine charts, and line balancing. These techniques were utilized to measure, analyze, and optimize the manpower utilization in the machining line.

2.1. Time and Motion Study

Time and motion study is defined as the examination of the techniques, materials, and tools and equipment utilized in carrying out a task. The analysis is done in order to identify the most cost-effective way to complete a task, standardize the methods, materials, tools, and equipment, precisely calculate the amount of time needed to complete the task by a qualified individual working at a normal pace and help train the worker in the new method (Barnes, 1949, as cited in Demirkesen et al., 2020; Mital et al., 2017).

2.1.1. Breaking down the elements

Observation in the production line was done to understand the tasks involved in the manufacturing process of the product. The researchers observed the machining line to determine the list and sequence of activities.

Each job or activity was recorded in writing. The emphasis was only on facts that are related to the existing method. Due to scheduling constraints, all observations were completed during the first shift. As all processes were operational on the first shift, the researchers were able to observe multiple processes simultaneously. By observing the processes that were in close proximity with each other, the researchers could observe and time four processes at a time. Short interviews were also conducted with the workers, line leader, and supervisor to understand the activities carried out in the line. This is important, as the workers are the most knowledgeable as to what happens in each process and how the output shafts are being processed.

2.1.2. Timing the elements

A time study was conducted at all processes in the line to document the list of activities in each process. It was done to meet the objectives, such as increasing the productivity, determining the production capacities, evaluating the standard cost, and balancing the activities through proper allocation or assignment. The start and end times of each operation were recorded using an electronic stopwatch.

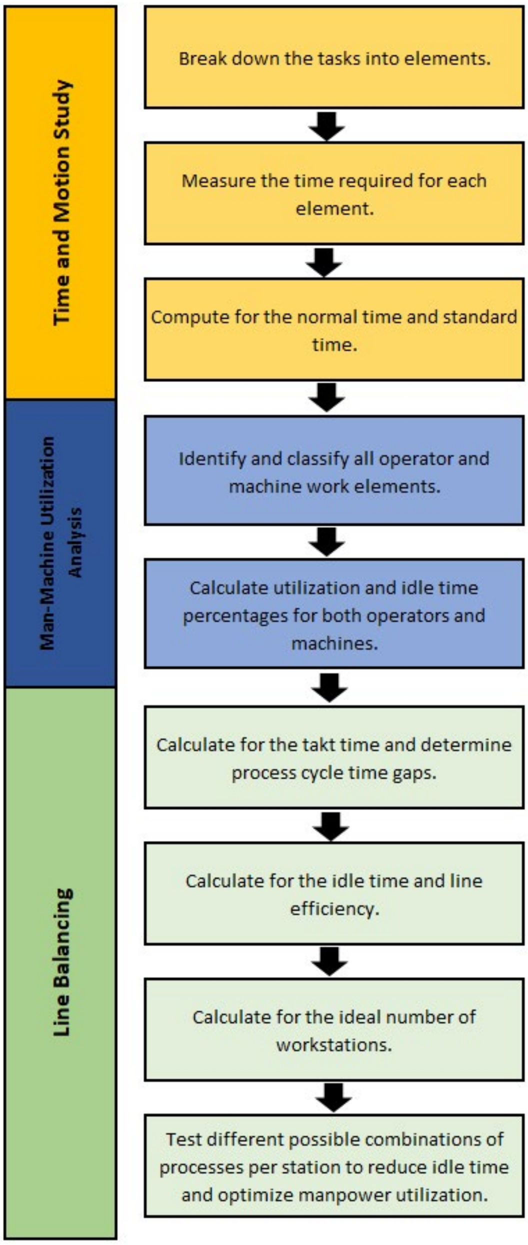

Figure 3: Step-by-step methodology.

Once the job was broken down into elements, it was determined how many times each element must be timed (Mital et al., 2017). A preliminary time study was conducted as presented in Table 1, and ratings and allowances were determined.

Table 1: Values for computing the number of trials.

Trial	Stopwatch Reading (x)	x^2
1	3.9	15.21
2	3.8	14.44
3	4.3	18.49
Total	12	48.14

The sample size, or the number of observations or readings for each element was determined using a statistical Equation (1) below, which is valid for a 95% confidence interval with 5% tolerance (Kanawaty, 1992; Cevikcan & Kilic, 2016; Mital et al., 2017):

$$N = \left(\frac{40\sqrt{N'\sum x^2 \left(\sum x\right)^2}}{\sum x} \right)^2 \quad (1)$$

$$N = \left(\frac{40\sqrt{3(48.14-144}}{12} \right)^2$$

N = 4.67 or 5 trials

Where:
N = number of observations
N' = number of trials during preliminary time study
x = summation of the recorded time

Five (5) trials were needed, or an additional 2 trials are necessary to get an absolute accuracy of 5%. Observed time was computed by getting the average time of the observations. Total observed time on the whole machining line to produce an output shaft is 10.24 minutes per unit, as shown in Table 2.

Table 2: Average observed time.

Processes	Average Observed Time (in minutes)			Total CT per Station
	Machine	Man	Travel	
Station 1				
Straightening	0.28	0.53	0.13	0.94
Washing	0.79	0.09	0.04	0.92
Gear Checking	0.59	0.2	0.08	0.87
Total	1.66	0.82	0.25	2.73
Station 2				
Grinding 1	1.05	0.3	0.04	1.39
Grinding 2	1.2	0.34	0.04	1.58
Total	2.25	0.64	0.08	2.97
Station 3				
Grinding 3	1.18	1.37	0.13	2.68
Internal Grinding	1.28	0.45	0.13	1.86
Total	2.46	1.82	0.26	4.54
Total observed time of the line				10.24

2.1.3. Computing the standard time

Standard has been used in manufacturing to determine the time required by an average skilled worker to perform the task using a prescribed method (Bongomin et al., 2020b). In this study, standard time is used to analyze standard work and to compare the before and after improvement implementation. The formulas applied in the computation of normal time and standard time were adapted from the study of Bongomin et al. (2020b).

Normal time was computed by multiplying the normal time by the rating, as shown in Equation (2).

$$\text{Normal time} = \text{Observed time x Rating} \quad (2)$$

The performance of the worker is assessed using the Westinghouse Rating System (Salvendy 2001, as cited in Cevikcan and Kilic, 2016), where four factors are considered in evaluating the performance of the worker; these are skills, effort, condition, and consistency. These factors are evaluated through the six (6) classes or categories with corresponding numeric values. Table 3 shows the performance rating given by the observer to each worker performing each process in the machining line.

Table 3: Performance Rating of the Worker

Process	Skill	Effort	Condition	Consistency	Rating
Straightening	0.11	0.10	0.04	0.00	1.25
Grinding process 1	0.11	0.10	0.00	0.00	1.21
Grinding Process 2	0.11	0.10	0.00	0.00	1.21
Grinding Process 3	0.11	0.10	0.00	0.00	1.21
Internal Grinding	0.11	0.10	0.00	0.00	1.21
Washing	0.11	0.10	0.04	0.0	1.25
Gear Checking	0.11	0.10	0.04	0.0	1.25

Standard time was computed by dividing the normal time by the difference of 1 minus the shift allowance, as shown in Equation (3) below:

$$\textit{Standard Time} = \frac{\textit{Normal Time}}{1 - \textit{Shift Allowances}} \quad (3)$$

Despite the increased mechanization and automation, numerous jobs still require effort from a human element. People who work on the shop floor, who are classified as both production line workers and employees in the supporting department, are known to be responsible for half of the increased productivity (Jilcha et al., 2015; Mahendran et al., 2022). That being said, allowances must be made for recovery from fatigue. The company employs a shift allowance of 13%, which includes 3% for tool change, 2% for housekeeping, 3% for fatigue, 3% for personal necessities, and 2% for stand-up meetings. The allowance percentage for personal needs and unavoidable delays set by the company is 13%.

Table 4: Observed time, Normal time, and Standard time.

Station	OT	PR	NT	ST
Station 1				
Straightening	0.93	1.25	1.18	1.35
Washing	0.92	1.25	1.15	1.32
Gear Checking	0.87	1.25	1.09	1.25
Total	2.73			3.92
Station 2				
Grinding 1	1.39	1.21	1.69	1.94
Grinding 2	1.58	1.21	1.92	2.21
Total	2.97			4.15
Station 3				
Grinding 3	2.68	1.21	3.24	3.72
Internal Grinding	1.86	1.21	2.25	2.59
Total	4.54			6.31

Note: OT = Observed Time; PR = Performance Rating;
NT = Normal Time; ST = Standard Time

Table 4 displays the computed observed time, performance rating, normal time, and standard time. Station 1 has a standard time of 3.91 minutes, station 2 has 4.14 minutes, and station 3 has the longest standard time of 6.32 minutes. Each station's standard time was added up to determine the overall standard time, which takes into account the worker's pace rating and allowances.

2.2. Man-Machine Utilization Analysis

The factors affecting production lines can be categorized into two: machine efficiency and manpower utilization (Subramanian et al., 2011). A man-machine activity chart is used to describe or plan the interactions between workers and machines over time. As the name indicates, the chart deals with the criteria of work elements and their time for both the worker and the machine. The typical input data for a man-machine chart would be the production process, such as loading, operating, and unloading the machine's components, as well as the duration of the aforementioned operations. The chart's output would assist manufacturing companies in achieving larger levels of productivity while using the same resources. The chart can be used to investigate potential process improvements. It can be used to illustrate delays and redundancy, so process improvement efforts can be made to eliminate inefficiencies and identify the activities that can be combined. (Kabir et al., 2013; Ramesh et al., 2019; Saravanakumar et al., 2021). The objective of this study in using the man-machine chart would be to determine the utilization ratio of man and machine. Utilization ratio shall be computed using the Equation (4):

$$\boldsymbol{Utilization} = \frac{\boldsymbol{WorkingTime}}{\boldsymbol{AvailableTime}} \times 100\% \tag{4}$$

Table 5: Man-Machine chart (Station 1).

Straightening			
Time (min.)	Man	Machine	Time (min.)
0.33	Unload	Idle	0.33
0.06	Cleaning	Idle	0.06
0.04	Load	Idle	0.04
0.01	Press M/C.	Idle	0.01
0.28	Idle	Machine Run	0.28
0.09	Unload	Idle	0.09
Washing			
Time (min.)	Man	Machine	Time (min.)
0.06	Load	Idle	0.06
0.01	Press M/C.	Idle	0.01
0.03	Unload	Idle	0.03
0.79	Idle	Machine Run	0.79
Gear Checking			
Time (min.)	Man	Machine	Time (min.)
0.06	Load	Idle	0.06
0.01	Press M/C.	Idle	0.01
0.1	Unload	Idle	0.1
0.03	Mark	Idle	0.03
0.59	Idle	Machine Run	0.59

Legends: Working
Not Working

Table 6: Working time (Station 1).

Process	Working Time	
	Man	Machine
Straightening	0.53	0.28
Washing	0.10	0.79
Gear checking	0.20	0.59
Total	0.83	1.66

Based on the interpretation of the man-machine chart as shown in Table 5 and Table 6, the utilization ratio of man is 38.97%, and the utilization ratio of machine is 61.03%. The utilization of the machine is 22.06% greater than the utilization ratio of the man in station 1. Therefore, the machines are more productive in time than the man is.

Table 7: Man-Machine charts (Station 2).

Grinding 1			
Time (min.)	Man	Machine	Time (min.)
0.07	Grease	Idle	0.07
0.07	Load	Idle	0.07
0.01	Press M/C.	Idle	0.01
1.05	Idle	Machine Run	1.05
0.06	Unload	Idle	0.06
0.1	Inspection	Idle	0.1
Grinding 2			
Time (min.)	Man	Machine	Time (min.)
0.11	Load	Idle	0.11
0.01	Press M/C.	Idle	0.01
0.09	Unload	Idle	0.09
0.13	Inspection	Idle	0.13
1.2	Idle	Machine Run	1.2

Legends: Working
Not Working

Table 8: Working Time (Station 2).

Process	Working time	
	Man	Machine
Grinding 1	0.31	1.05
Grinding 2	0.34	1.20
Total	0.65	2.25

Based on the interpretation of the man-machine chart as shown in Table 7 and Table 8, the utilization ratio of man is 24.50%, and the utilization ratio of machine is 75.50%. The utilization of machines is 51% greater than the utilization ratio of men. Therefore, the machines are more productive than the man does on station 2.

Table 9: Man-Machine charts (Station 3).

Grinding 3			
Time (min.)	Man	Machine	Time (min.)
0.11	Load	Idle	0.11
0.01	Press M/C.	Idle	0.01
0.12	Unload	Idle	0.12
1.13	Inspection	Idle	1.13
1.18	Idle	Machine Run	1.18
Internal Grinding			
Time (min.)	Man	Machine	Time (min.)
0.3	Load	Idle	0.3
0.01	Press M/C.	Idle	0.01
0.07	Unload	Idle	0.07
0.09	Inspection	Idle	0.09
1.28	Idle	Machine Run	1.28

Legends: Working
Not Working

Table 10: Working time (Station 3).

Process	Working time	
	Man	Machine
Grinding 1	1.37	1.18
Grinding 2	0.47	1.28
Total	1.84	2.46

Based on the computation of the man-machine chart as shown in Table 9 and Table 10, the utilization ratio of man is 45.81%, and the utilization ratio of machine is 54.19%. The utilization of machine is 8.38% greater than the utilization ratio of man. Therefore, the machines are more productive than the man does on station 3.

Table 11: Utilization of Man and Machine.

Station	Utilization	
	Man	Machine
Station 1	33.33%	66.67%
Station 2	22.41%	77.59%
Station 3	42.79%	57.21%
Total	34.26%	65.74%

Table 11 shows the average utilization ratio of man, which is 32.44%, and the utilization ratio of machine is 67.56%. The utilization of machines is 35.12% greater than the utilization ratio of man. Therefore, the machine has more productive time than the man does on the whole machining line. With station 3 having the highest manpower utilization and station 2 having the least.

2.3. Line balancing

Balancing the manufacturing line can increase the utilization of manpower. To determine the assembly lines' cycle time and operator count, line balancing was used (Teshome et al., 2023). The task can be distributed evenly across the workstation using line balancing to reduce workers' idle time. To achieve an optimal or most efficient balance of the capacities and flows of the production processes, line balancing attempts to arrange the workers in an efficient pattern. To ascertain the number of workstations and idle time in each workstation, various values must be acquired (Kumar & Mahto, 2013). Provided the current work setup as indicated in Figure 2, line balancing assessment was conducted. Various computations, such as takt time, number of work stations, idle time, and line efficiency, utilized the same formula adapted from the study of Bongomin et al. (2020b).

Takt time is obtained via Equation (5), wherein the available working hours are divided by the required output per day, which, according to the company, is 80 units per day.

$$Takt\ time = \frac{Available\ working\ hours}{Required\ output\ per\ day} \quad (5)$$

$$Takttime = \frac{450mins}{80units}$$

Takt time = 5.63 min per unit

The computed takt time is 5.63 minutes. This means that each workstation should produce a unit within 5.63 minutes. Based on the calculation done for takt time and the cycle time for the process, a graphical representation in the form of a time bar graph can be produced, clearly showing the gap between the takt time and the cycle time of the process blocks.

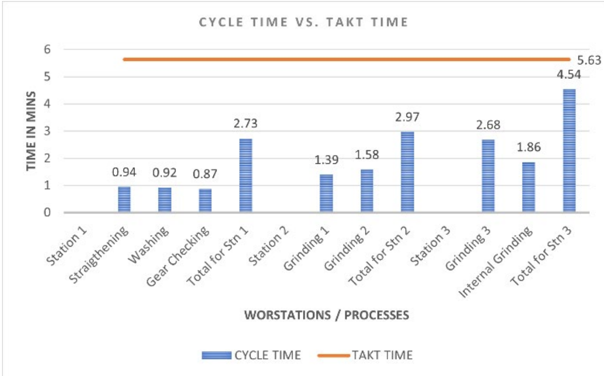

Figure 4: Representation of Cycle time vs. Takt time.

Shown in Figure 4 is the gap between the cycle time and takt time. To be able to investigate more line balance alternatives, job sizes or processing times should be maintained reasonably minimal in comparison to takt time (Gong et al., 2014; Didden et al., 2022). All processes are below or did not exceed the takt time; however, it shows an imbalance of workload in each workstation. Station 3 has a longer processing time than stations 1 and 2, whereas straightening, washing, and gear-checking processes in station 1 have the shortest processing times of any workstation. Idle time per workstation was also determined. The idle time was computed using Equation (6) as follows:

$$Idle\ time = W_{actual}(Longest\ Cycle\ Time) - \sum Cycle\ Time \quad (6)$$

Where W_{actual} = number of actual workstations

Idle time = 3(4.54 min) – 10.24 min

Idle time = 3.38 min

Line efficiency is computed using Equation (7):

$$Lineefficiency = \frac{TotalCycletime}{W_{Actual} \times LongestCT} \quad (7)$$

$$LineEfficiency = \frac{10.24mins.}{3 \times 4.54mins}$$

Line efficiency = 0.7518 or 75.18%

The computed idle time is 3.38 minutes and constitutes 24.82% of the total working time. To reduce the idle time and further improve the manpower utilization, the researchers plan to reduce the manpower allocation and reassign the workstations. To determine the ideal number of workstations, it is computed through Equation (8):

$$No.ofWorkstation = \frac{\sum CycleTime}{Takttime} \quad (8)$$

$$No.ofWorkstation = \frac{10.24mins.}{5.63mins}$$

No. of Workstation = 1.82 or 2

As computed, the workstation can be reduced from three (3) to two (2). The current manpower allocation in each workstation shall be changed to reduce the cycle time and improve the manpower utilization.

3. Results and discussion

3.1. Analysis of alternatives

A manpower plan was drawn to increase the utilization of man. All possible combinations of processes per station are considered to find the most optimal manpower allocation, where manpower utilization shall be improved and idle time shall be reduced.

3.1.1. Alternative no. 1

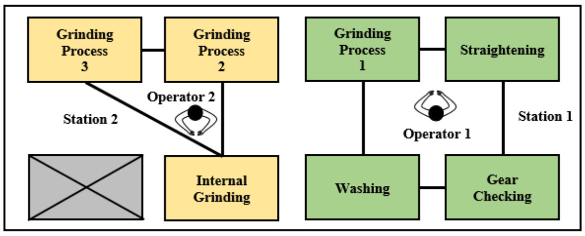

Figure 5: Proposed manpower allocation 1.

The recommended manpower allocation for alternative 1 includes two workstations with one worker each. Station 1 consisted of straightening, grinding process 1, washing, and gear inspection, while station 2 included grinding processes 2 and 3 and internal grinding. While station 1 permits workers to travel among four machines on either side of the station, station 2 allows workers access to three machines with internal grinding and grinding processes 3 more distant from one another. Given the above setup, the total cycle time for both workstations was calculated, taking into account each worker's time to travel from one machine to another. The same approach to cycle computation was used for the remaining alternatives.

Table 12: Total Cycle time computed for Alternative 1 (in min).

Alternative 1	Machine	Man	Travel Time	Total Ct Per Station	Total Cycle Time
Station 1					10.13
Straightening	0.28	0.53	0.04	0.84	
GP1	1.05	0.30	0.08	1.43	
Washing	0.79	0.09	0.04	0.92	
Gear Checking	0.59	0.20	0.08	0.87	
Total	2.71	1.12	0.24	4.07	
Station 2					
GP2	1.20	0.34	0.04	1.58	
GP3	1.18	1.37	0.13	2.68	
Internal Grinding	1.28	0.45	0.08	1.81	
Total	3.66	2.16	0.25	6.07	

As shown in Table 12, station 1, which consisted of 4 processes, has a total cycle time of 4.07 minutes. While station 2 is taking slightly longer with 6.07 minutes. The cumulative cycle time is 10.14 minutes.

Table 13: Summary of Cycle Time (Alternative 1).

	Cycle time (min)	
Stations	Man	Machine
Station 1	1.36	2.71
Station 2	2.41	3.66
Total	3.77	6.37

Given the sum of both man and machine cycle time in Table 13, utilization rate can be computed. Thus, the utilization rate of man in station 1 is 33.42%, while the utilization of the machine is at 66.58%. For station 2, utilization of man is at 39.70%, and utilization of machine is 60.30%. All in all, the utilization of man computed in alternative 1 is 37.18%, which is 2.92% higher than the current manpower utilization. It also has a total idle time of 2.01 minutes with a percentage of 16.56%.

3.1.2. Alternative no. 2

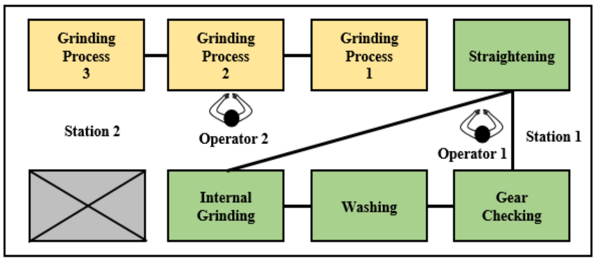

Figure 6: Proposed manpower allocation 2.

Figure 6 illustrates the proposed manpower allocation for alternative 2, consisting of 2 workers and workstations. Station 1 has 4 processes, which are straightening, internal grinding, washing, and gear checking. While station 2 is managed by the 2nd worker operating the grinding processes 1, 2, and 3 with machines arranged linearly from left to right.

Table 14: Total Cycle Time Computed for Alternative 2 (in min).

Alternative 2	Machine	Man	Travel Time	Total Per Station	Total Cycle Time
Station 1					10.38
Straightening	0.28	0.53	0.25	1.05	
Internal Grinding	1.28	0.45	0.04	1.77	
Washing	0.79	0.09	0.04	0.92	
Gear Checking	0.59	0.20	0.08	0.87	
Total	2.94	1.27	0.41	4.61	
Station 2					
GP1	1.05	0.30	0.04	1.39	
GP2	1.20	0.34	0.04	1.58	
GP3	1.18	1.37	0.25	2.80	
Total	3.43	2.01	0.33	5.77	

A total cycle time of 4.61 minutes is recorded for station 1 and 5.78 minutes for station 2, as indicated in Table 14. The cumulative cycle time is 10.39 minutes. Given the number of machines the operator travels from and the distance between the internal grinding machine and the straightening machine, the time needed to travel in station 1 is significantly longer than in station 2.

Table 15: Summary of Cycle Time (Alternative 2).

Stations	Cycle Time (Min)	
	Man	Machine
Station 1	1.68	2.94
Station 2	2.34	3.43
Total	4.02	6.37

Table 15 contains the total of the man and machine cycle times. The machine utilization rate in station 1 is 63.64%, but the man utilization rate is 36.36%. The machine utilization rate at station 2 is 59.45%, whereas the man utilization rate is 40.55%. Overall, the manpower utilization calculated in alternative 2 is 38.69%, which is 4.43% greater than the current manpower utilization. Additionally, it has 1.16 minutes of total idle time or 10.05% of the total working time.

3.1.3. Alternative no. 3

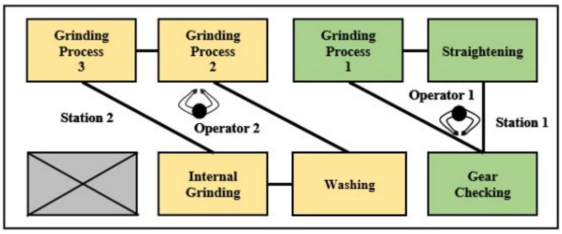

Figure 7: Proposed manpower allocation 3.

The proposed manpower allocation for alternative 3 consists of 2 workers and workstations as shown in Figure 7. Station 1 has 3 processes composed of straightening, grinding process 1, and gear checking. While Station 2 consists of 4 processes, including grinding processes 1, 2, and 3 and washing. With this setup, the worker in station 2 travels diagonally from grinding processes 3 and 2 to the internal grinding machine and washing. While station 1 has shorter travels with only 3 machines adjacent to each other.

Table 16: Total Cycle Time Computed for Alternative 3 (in min).

Alternative 3	Machine	Man	Travel Time	Total Per Station	Total Cycle Time
Station 1					
Straightening	0.28	0.53	0.04	0.84	
Gp1	1.05	0.30	0.13	1.48	
Gear Checking	0.59	0.20	0.08	0.87	
Total	1.92	1.03	0.25	3.19	
Station 2					10.24
Gp2	1.20	0.34	0.04	1.58	
Gp3	1.18	1.37	0.13	2.68	
Internal Grinding	1.28	0.45	0.04	1.77	
Washing	0.79	0.09	0.13	1.01	
Total	4.45	2.25	0.34	7.04	

Table 16 shows a total cycle time of 3.20 minutes for station 1 and 7.04 minutes for station 2. The whole cycle time is 10.24 minutes. Travel time in station 2 is longer as expected due to the distances and number of machines the worker needs to travel on.

Table 17: Summary of Cycle Time (Alternative 3).

Stations	Cycle Time (Min)	
	Man	Machine
Station 1	1.28	1.92
Station 2	2.59	4.45
Total	3.87	6.37

Table 17 contains the total of the man and machine cycle times. The machine utilization rate in station 1 is 60%, thus, the man utilization rate is 40%. The machine utilization rate at station 2 is 63.21%, whereas the man utilization rate is 39.79%. Overall, the manpower utilization calculated in alternative 1 is 37.79%, which is 3.53% greater than the manpower utilization that is already in place. A total idle time of 3.85 minutes was computed or 27.34% of the total time.

3.1.4. Alternative no. 4

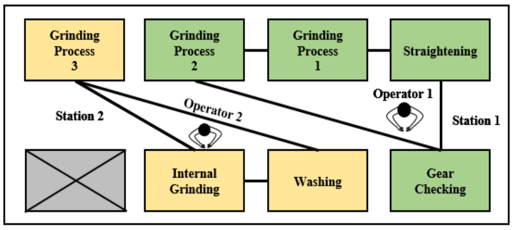

Figure 8: Proposed manpower allocation 4.

As displayed in Figure 8, the proposed manpower allocation for alternative 4 consists of 2 workers and workstations. Station 1 is composed of straightening, grinding processes 1 and 2, and gear checking. While Station 2 consists of grinding process 3, internal grinding, and washing. Station 1 has a slightly longer diagonal path between internal grinding and grinding process 2 compared to the diagonal path in station 2 between grinding process 3 and washing.

Table 18: Total Cycle Time Computed for Alternative 4 (in min).

Alternative 4	Machine	Man	Travel Time	Total Per Station	Total Cycle Time
Station 1					
Straightening	0.28	0.53	0.04	0.84	
Gp1	1.05	0.30	0.04	1.39	
Gp2	1.20	0.34	0.25	1.79	
Gear Checking	0.59	0.20	0.08	0.87	
Total	3.12	1.37	0.41	4.89	10.48
Station 2					
Gp3	1.18	1.37	0.13	2.68	
Internal Grinding	1.28	0.45	0.04	1.77	
Washing	0.79	0.09	0.25	1.13	
Total	3.25	1.91	0.42	5.58	

As shown in Table 18, station 1 has a total machine cycle time of 3.12 minutes, man time of 1.37 minutes and travel time of 0.41 minutes, resulting in a total cycle time of 4.90 minutes. Station 2 with slightly higher cycle time of 5.58 minutes, composed of 3.25 minutes of machine time, 1.91 minutes man time and 0.42 minutes travel time.

Table 19: Summary of Cycle Time (Alternative 4).

Stations	Cycle Time (Min) Man	Cycle Time (Min) Machine
Station 1	1.78	3.12
Station 2	2.33	3.25
Total	4.11	6.37

Alternative 4 has a manpower utilization of 36.33% in station 1 and 41.76% in station 2. The overall utilization of manpower computed in alternative 4 is 39.22%, which is 4.96% higher than the current manpower utilization. Idle time computed is 0.69 minutes only, comprising 6.18% of the total time.

1.1.1. Alternative no. 5

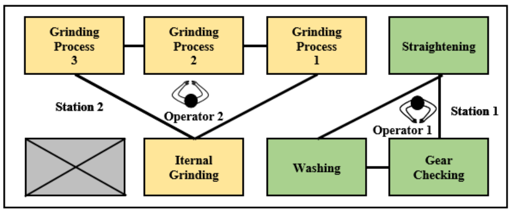

Figure 9: Proposed manpower allocation 5.

Figure 9 illustrates the proposed manpower allocation for alternative 5 with 2 workers and workstations. Station 1 composed of straightening, washing and gear checking. While Station 2 consist of grinding process 1, 2, 3 and internal grinding. Station 1 has fewer machines, with 3 and a shorter path to travel, while station 2 has the 3 grinding processes arranged linearly, as well as the internal grinding process adjacent to the other side of the line.

Table 20: Total Cycle Time Computed for Alternative 5 (in min).

Alternative 5	Machine	Man	Travel Time	Total Per Station	Total Cycle Time
Station 1					
Straightening	0.28	0.53	0.13	0.93	
Gear Checking	0.59	0.20	0.08	0.87	
Washing	0.79	0.09	0.04	0.92	
Total	1.66	0.82	0.25	2.72	
Station 2					10.23
Gp1	1.05	0.30	0.04	1.39	
Gp2	1.20	0.34	0.04	1.58	
Gp3	1.18	1.37	0.13	2.68	
Internal Grinding	1.28	0.45	0.13	1.86	
Total	4.71	2.46	0.34	7.51	

Given the number of machines per station, station 2 reflects higher cycle time than station 1, as shown in Table 20. Station 1 has a total machine cycle time of 1.66 minutes, man cycle time of 0.81 minutes and travel time of 0.25 minutes, resulting in a total cycle time of 2.72 minutes. Station 2 with higher cycle time of 7.52 minutes, composed of 4.71 minutes of machine time, 2.47 minutes man cycle time and 0.34 minutes travel time.

Table 21: Summary of Cycle Time (Alternative 5).

Stations	Cycle Time (Min) Man	Cycle Time (Min) Machine
Station 1	1.07	1.66
Station 2	2.80	4.71
Total	3.87	6.37

Alternative 5 has a manpower utilization of 39.19% in station 1 and 37.28% in station 2. The overall utilization of man computed in alternative 5 is 37.79%, which is 3.53% higher that than the current manpower utilization. Alternative 5 has a total idle time of 4.79 minutes with a percentage of 31.89%.

3.1.5. Comparison of alternatives

Table 22: Comparison of alternatives.

Variables	Current	Alternatives 1	2	3	4	5
No. Of Worker Or Workstation	3	2	2	2	2	2
Utilization Of Man (%)	34.26	37.18	38.69	37.79	39.22	37.79
Utilization Of Machine (%)	65.74	62.82	61.31	62.19	60.78	62.21
Cycle Time (Min)	10.24	10.13	10.38	10.23	10.47	10.23
Longest Cycle Time (Min)	4.54	6.07	5.78	7.04	5.58	7.51
Idle Time (Min)	3.38	2.01	1.16	3.85	0.69	4.79
Idle Time %	24.82	16.56	10.05	17.34	6.18	31.89

Shown on Table 22 is the comparison of results between the current manpower allocation and the five (5) alternatives. After reducing the manpower and workstation from three (3) to two (2), several factors vary per alternatives. Alternative 4 has the highest manpower utilization with 39.22% which is 4.96% higher than the current setup. It was followed by alternative 2 with 38.69%, then, alternative 3 and 5 with both 37.79%. and lastly, alternative 1 with 37.18%. Alternative 4 also has the highest cycle time computed with 10.47 minutes but with the shortest bottleneck which is 5.58 minutes. In terms of idle time, alternative 4 has the lowest idle time of 0.69 minutes or 6.18% while alternative 5 has the longest idle time of 4.79 minutes or 31.89%. The evaluation of alternatives revealed that idle time cannot be totally eliminated, which is aligned with the study of Jamil & Razali (2016). It is because the application of line balancing in a manufacturing company should take into account certain circumstances or exempt some factors from changes in order to sustain the product's quality and the process requirements. In this study, factors such as the frequency of inspection, the number of machines, and the machine speed were maintained.

The alternatives exhibit varying outcomes following evaluation. While manpower utilization has improved in some of the alternatives, other aspects such as cycle time, bottlenecks, and idle time have not yielded the anticipated outcomes. An increase in travel time of the worker from one machine to another was anticipated due to the reduction from 3 to 2 manpower, each worker has an extra machine to go into during the operation. Thus, most of the proposed alternatives have an increase in cycle time and exceeded the takt time. A study by Didden et al. (2022) concentrated on the use of a proportional cycle time constraint, which permits operators to surpass the takt time to a certain degree, provided that the takt time is fulfilled on average (based on the demands of each model). They showed that the quality and efficiency of a production line can be improved by removing huge setup times and maintaining the processing times relatively short in relation to the takt time.

Building on this concept, proportionate cycle time constraint could also be applied in this study, given that the average cycle time of all alternatives did not exceed the takt time. But considering the risks of the bottleneck and idle time, alternative 4 is the only one that maintained the smallest gap and did not surpass the takt time compared to other alternatives. Though all alternatives have only two (2) workers and workstations, alternative 4 has the most improved manpower utilization—resulting in a much more evenly distributed workload.

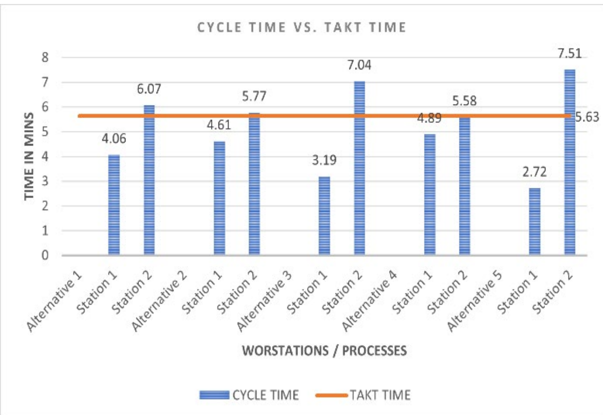

Figure 10: Representation of cycle time and takt time per station per alternatives.

Standard time for alternative 4 is established to compare the current and proposed manpower allocation as shown in Table 23. Only the standard time of straightening process decreased from 1.35 to 1.21 minutes. While the standard time of grinding process 1, 2, 3, internal grinding, and gear checking remain the same. The washing process has higher standard time compare to their current state, from 1.32 to 1.62 minutes. The computed standard time for the proposed alternative has an increase of 0.16 minutes compare to the current. This means that the time required to do the task by an average worker is 2.31% longer with the proposed alternative. Increase in processing time is due to the reduction of 1 worker from the machining line as mentioned.

Table 23: Standard time per process of current and proposed alternative.

	Standard Time (Min)	
Process	Current	Proposed
Straightening	1.35	1.21
Gp1	1.94	1.94
Gp2	2.21	2.21
Gp3	3.72	3.72
Internal Grinding	2.59	2.59
Washing	1.32	1.62
Gear Checking	1.25	1.25
Total	14.38	14.54

As compared to the study of Kumar et al. (2023), where significant improvements were achieved by minimizing distance between workstations—allowing workers to operate the machine without interruption and with shorter workpiece travel—this study shows a different strategy. Despite a minimal increase in job length as computed, this was compensated by a more equitable distribution of tasks across the process, reduced idle time, and optimal man-to-machine allocation that enhances overall manpower utilization and line efficiency.

4. Conclusion and recommendation

The company has experiencing workload imbalance and idle time in their machining line for output shaft due their current manpower allocation. The manpower was not optimally utilized per workstation as other workers has less workload. The issues were determined through observation, interview and time and motion study. After conducting a time study, cycle time in each process in each workstation was determined. Man and machine cycle times obtained were used to construct man-machine chart. The chart was used to assess the utilization ratio of man and machine. It was found out that the utilization ratio of the machine is greater than the utilization ratio of the man. Thus, the machine is more productive than the man, resulting in idle time as the worker waits for the machine to complete its cycle. To further improve the utilization of manpower, the researchers used line balancing and found out that the production line can be reduced from three (3) to two (2) workstations with one (1) worker each. Five (5) alternatives were drawn to find the most optimal possible manpower assignment to be implemented. The implementation of a new manpower assignment plan also denotes changes in cycle time and idle time. As the manpower allocation changes per alternative, both manpower and machine utilization vary. The allocation of processes per workstation greatly affects the manpower utilization. Some factors are also affected as man cycle time changes due to travel time.

In all, this study was able to apply a data-driven approach in improving utilization and eliminating inefficiencies in the machining line of an automotive parts manufacturing company. The suggested alternative not only balanced the workload but also optimized operations by reducing idle time and combining workstations. For future studies, it is suggested to test the application of the presented setup via actual production experiments in order to determine long-term effect on output and worker efficiency. Further research may also investigate the implementation of automation, ergonomics studies, and real-time monitoring systems as a means to further increase productivity and aid data-driven decision-making within automotive parts manufacturing settings.

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Conflicts of Interest

The authors declare no conflicts of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Quillbot in order to correct grammatical errors and enhance sentence construction for better understanding. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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