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Job allocation and idle time reduction using a worker-machine relationship-based strategy for sustainable management in a machine shop

Shiela Mhay R. Dalisay[1], Arnie Lyn D. Alagos[2], Charmine Sheena R. Saflor[3], Klint Allen A. Marinas[4], Yung- Tsan Jou[5]

[1,2] Department of Industrial Engineering, Occidental Mindoro State College, Philippines
[3,4,5] Department of Industrial and Systems Engineering, Chung Yuan Christian University, Taiwan

Abstract

In a machine shop, operation cost is commonly high, and resources are limited; thus, establishing a sustainable management plan will require utilizing resources effectively and efficiently. Optimizing the service operation should promote the synchrony of workers with job allocation and reduce the anticipated equipment operation cost. This study applies quantitative tools of methods engineering, worker and machine relationship with descriptive research design of observational method with an overt observational approach in one of the established machine shops in Oriental Mindoro, Philippines. A total of fifteen workers, wherein ten operators are observed based on their working cycle and duration, taking into account their wages and machine cost in a random and synchronous servicing approach. The study discovered the current ideal distribution of machine-operator in addition to job re-assignment among workers and proposed suggestions for the shortcomings of the worker-machine relationship-based strategy. Moreover, the findings of this research paper will be used as a reference for further studies on improving machine and operator productivity to lower production costs.

Keywords: *Overt Observational Approach; Methods Engineering; Random Servicing; Synchronous Servicing; Sustainable Management.*

INTRODUCTION

Due to today's complicated and dynamic business field, firms must carefully create and develop business strategies to obtain a long-term competitive advantage. It is vital to formulate as well as establish various techniques in the business industry (Chrigwin, 2016) since organizations without a plan are unable to use resources effectively and efficiently because of a lack of ability to conduct a strategic analysis that will allow making the best use of business financial and human resources (Durmaz, & Düşün, 2016). Sustainable management entails considering environmental concerns while making decisions and formulating strategies (Garner, 2021). Managing company sustainability benefits the environment and the local community long term. In addition, it has other advantages, such as enhanced employee morale, profitability, and recruitment. It is becoming a more crucial goal for decision-making in global corporations (Bhinge et al., 2015). It affects commercial establishments' economic condition and technological development by limiting resources and increasing trade competition. According to Merkus (2019), the result of the

Corresponding author
Shiela Mhay R. Dalisay, dalisayshielamhay@gmail.com
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implementation of the new strategy will help to reshape organizational operations to remain competitive, which causes the implementation of a new strategy as crucial to coping with business mechanisms.

Manufacturing businesses are under pressure to optimize their output to reduce costs and boost efficiency (Denkena et al., 2014). Optimization is essential in business (Dostal, 2013) as it helps reduce costs that can lead to higher profits to the establishment's success and the most necessary tools for achieving sustainability. Sadolla (2020) pointed out that optimizing complex subjects that demand precise computing for solutions must consider much information, such as principles and notions for designing artificial computational processes. Recent studies in machine shops focus primarily on promoting production schedules such as maximizing total early work (Chen et al., 2021) and energy optimization in flexible machining with dynamic nature (Li et al., 2020), which emphasized the use of algorithms on machine variables and production output.

According to Jin & Kite-Powell, (2000), machine tools and other materials exhibited in production are needed for a workforce to finish one job. However, it is the worker's performance that attests to the quality of machine shop operation. Interaction between the worker and machine can be optimized by analyzing the relationship between the operator's working cycle and the machine's operating cycle. Recorded sequence elements throughout the procedure are critical in obtaining the relationship between the operator's working cycle and the machine's operating cycle (Freivalds, 2009; Meller and Gau, 1996; Phillips, 1997). Moreover, this study employed a gang process chart to record the frequent work distribution, including the machine operation, parts assembly, monitoring, and transportation.

Machine shop in Calapan, Oriental Mindoro, the Calapan Oriental Machine & Engineering COME, offers services including engine reconditioning such as crankshaft, engine block, cylinder head, and fabrication services of the machine parts. With the growing number of service operations, the unit and type of machine keep increasing for three decades. In order to cope with the gaining operating expenses, the company chose to maintain the bare minimum workforce and invest in the versatility of skill requirements. This study aimed to optimize the overall operation on shop-floor by reducing the idle time of workers both on manual labor and machining and minimizing the cost per machine operation by assigning suitable operators on the right unit/s of the machine, considering the dynamic sharing of work distribution and prolonged machine operation, With the proper worker set-up focusing on the overall productivity, sustainable management with a lesser impact on the environment by consuming less energy and profitable enough by increasing the output with a similar amount of input is plausible.

LITERATURE REVIEW

2.1 Sustainable Management Strategy

According to the World Commission on Environment and Development's report, humankind currently faces economic, social, and environmental risks. Human beings must be able to continue to grow and meet their current demands, but this should not come at the expense of the next generation's well-being. The ideals of fairness, sustainability, and commonality can be used to achieve this (Costanza, 1995). Sustainability is a complex concept (Aragon-Correa *et al.* 2017), and to minimize confusion, Pantelic (2016) pointed out that researchers must be specific when utilizing the idea of sustainability. On the other hand, the general measure of company performance can be

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separated into three dimensions: financial, business, and organizational performance (Venkatraman *et al.* 1986).

Nevertheless, pursuing sustainability is crucial not only for a society's environmental circumstances and welfare but also from a company standpoint, as legal requirements and stakeholder pressures demand greater environmental and social responsibility (Winkler, 2010). Stakeholders such as employees must maximize their beneficial benefits while reducing the negative ones. Many companies have spent on social responsibility and social welfare in order to improve their performance in areas related to social challenges.

Moreover, many firms recognize the need to manage their social and environmental performance. The corporation follows a corporate strategy that takes into account social, environmental, and economic factors (Polychronopoulos *et al.,* 2021). Workers' performance usually depends on whether a business' successfully achieves financial goals resulting entire company failing to move towards effective implementation of sustainability (Ali, 2020). Thus, companies should design a sustainability plan to enhance the organizational structure and merge the strategies in order to become more sustainability-oriented (Kennedy, Whiteman, & van den Ende, 2017). It will become sustainable when leaders can devise methods to boost market share, talent, and stakeholder benefits while lowering operational costs and job dissatisfaction (Banker *et al.,* 2014), and a company is considered to be sustainable if it continues to exist in the face of market risks and internal change.

2.2 Application of Worker-Machine Relationship and Gang Chart

The worker and machine process chart allows analysts to observe the exact time relationship between the working cycle of the operator and the operating cycle of the machine (Freivalds, 2009, Meller and Gau, 1996; Phillips, 1997). The relationship between the machine/s and operator/s is measured via time duration during manual loading, machine operation, and travel between machines in regards to the rate of operator and machine operating cost. It is a type of quantitative and recording tool in methods engineering composed of three approaches, and the study employed synchronous and random servicing. Synchronous servicing refers to assigning more than one machine to an operator where both machine and worker are occupied during the whole cycle. The ideal number (n) of machines per operator is derived by using the time (min.) it takes to load/unload manually (l), operate the machine (m), and travel (w) from one machine to another (1). Commonly the resulting digits are in decimal form; hence realistically, machine units are in the whole number (2) and or round-up value of a decimal number (3). With two options for an ideal number of units, the total expected costs are anticipated and compared, choosing the less expensive as a better deal.

$$n = \frac{(l+m)}{(l+w)} \quad (1) \qquad TEC_{n1} = \left[\frac{(l+m)(K_1 + n_1K_2)}{n_1}\right]\left(\frac{1}{60}\right) \quad (2) \qquad TEC_{n2} = [(l+w)(K_1 + n_2K_2)]\left(\frac{1}{60}\right) \quad (3)$$

On the other hand, random servicing is when it is not known when a facility needs to be serviced or how long service takes (Freivalds, 2009). It considers the probability of machine breakdown (m) out of the set (n) and the capacity of operator/s to tend the breakdown. The

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sequential terms of binomial expansion (4) provide the likelihood of downtime (p) supposing in random times in the day and run time (q = 1-p) where n is moderately small. It takes into account the hourly rate of the operator (K1), the hourly rate of the machine (K_2), the number of machines (n), and the production rate (R) of pieces from the machine per hour (5).

$$p(m\ of\ n) = \frac{n!}{m!\,(n-m)!}(p^m q^{n-m}) \quad (4) \qquad TEC = \frac{K_1 + nK_2}{R} \quad (5)$$

Concerning the methods of engineering used in optimizing operations, the scientific process relies heavily on accurate record-keeping (Steneck, 2004). Gang process chart record the activities completed per individual in the group. It measured the workload via time duration of the working cycle and distinguished idle time during the standby period. Moreover, it is a comparative chart and allows work distribution based on the task condition. The following section discusses the process of data collection and analysis.

RESEARCH METHOD

3.1 Research design/ paradigm

This study used a descriptive research design of an observational method with an overt observational approach. The research was conducted in one of the well-established machine shops in Calapan, Oriental Mindoro, the Calapan Oriental Machine & Engineering (COME), from March to April 2021.

3.2 Participants

A total of 15 workers from the machine shop were observed. The participants were directly involved in the service operations such as reconditioning crankshaft, engine block, cylinder head, and fabrication services of machine parts. And the general process of automotive services.

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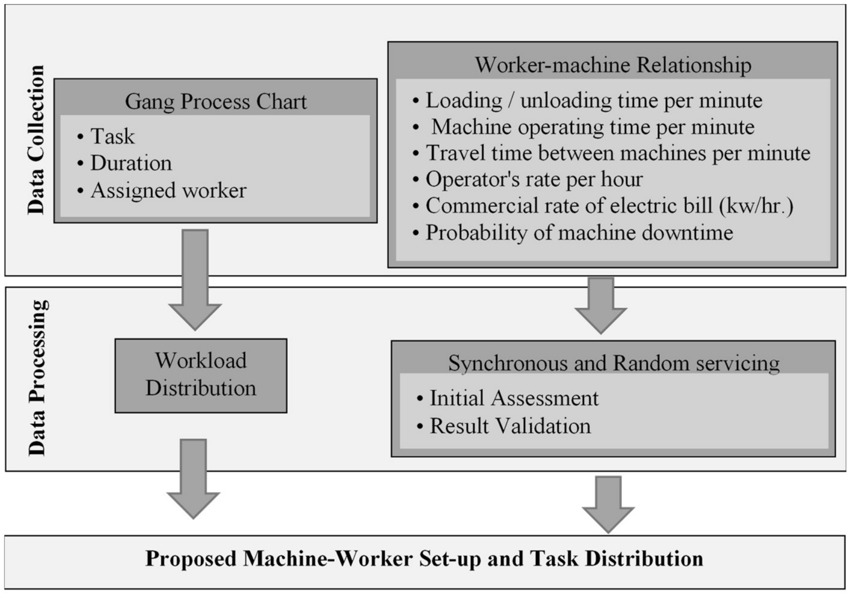

Figure 1. Research Methodology Flow Chart

3.3 Data gathering

The overt observational method was used in recording the flow of the process, workers' performance, and machine operation. In recording the duration and name of a task in a flow process, we utilized the software Workstudy+6. We also interviewed involved workers regarding their wages, frequency of machine downtime on operators, and a commercial rate of electric billing on managers.

3.4 Data interpretation

With the use gang process chart, the amount of workload was determined inversely by the duration of idle time. The initial synchronous servicing (n) results were considered to be the ideal number of machines per worker based on the duration of workers' performances and machine operation. Total expected costs were compared (n1 = least whole number, n2 = round-up value) to determine the ideal number in case the result was in decimal form, with lesser cost the better option. The probability of machine downtime out of a given number of machines is assumed to be random during the day in random servicing. The option offering less cost will be considered an ideal choice in assigning operator/s on a group of machines. The results will be in charts and figures; we will interpret the data by describing the contents and explaining the circumstances highlighted in the chart or figure.

FINDINGS AND DISCUSSION

4.1 Job distribution

In assessing the job distribution of 15 workers of Calapan Oriental Machine & Engineering, figure 2.a displays the gang process chart, and figure 2.b supplies the performed task of each worker for a period of 8 hours. The total idle time for the present method is 29.73 hours. According to

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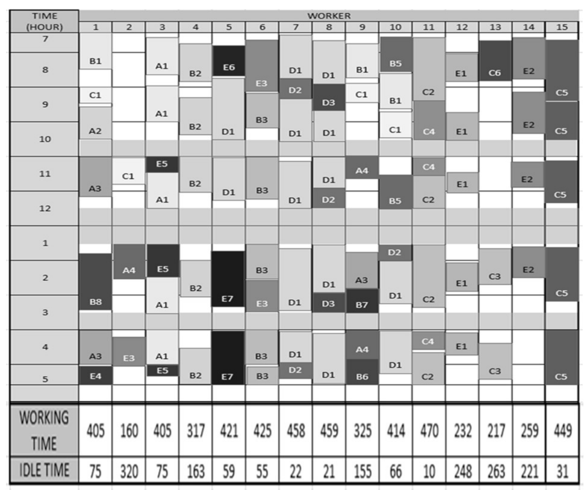
Freivalds (2009), a gang process chart records the duration and tasks of multiple workers at a given work period. It provides a holistic view of the process and allows wide-ranged alteration in the task distribution to make the operation more efficient and systematic. Commonly, the utilization of a gang process chart leads to the assignment of personnel to the right set of tasks, thereby maximizing the rate of output and minimizing the standby period or idle time.

In this study, the proposed method maintained the total idle time of the present method instead of reducing the idle time of service operation. It is due to the singular setup of work-sharing where the completion of one service operation involves multiple workers. Optimization can be achieved by transferring the workload fairly to each worker. Workers 3, 4, 6, 7, 8, 10, and 15 were fixed operators of machines (figure3), worker 11 was fixed in performing valve seat setting and assembling of the cylinder head (figure 4), and workers 12 & 14 were record keepers and drivers that performed their task apart from the main operation (figure 5). Only the remaining worker 1, 2, 5, 9, and 13 can perform dynamically and be assigned other operation tasks, and among these groups of workers, only workers 2 and 13 were the least loaded (figure 6). Idle time can only be reduced individually, but the total idle time will remain the same.

Other		Crankshaft Operation		Engine Block Operation		Cylinder Head Operation		Machine Shop Operation	
E1	Checklist	A1	Operation of Cranksahft Grinding Machine	B1	Washing of engine block	C1	Washing cylinder head	D1	Operation of Lathe Machine
E2	Driver	A2	Washing of crankshaft	B2	Operation of Boring Machine	C2	Valve seat setting	D2	Welding
E3	Drilling	A3	Assembling crankshaft to engine block	B3	Operation of Honing Machine	C3	Valve seat sealing	D3	Grinding
E4	Sweeping	A4	Asisst	B4	Washing of engine block	C4	Assembing		
E5	Guide junior			B5	Assembling of piston and connecting rod	C5	Cylinder head reface		
E6	Consult senior			B6	Fitting to engine block	C6	Valve seat cutting machine		
E7	Cleaning machine			B7	Assembling of entire engine block				
				B8	Operation of Camshaft Grinding Machine/ Polish				



a. b.

Figure 2. Gang process chart for on period of 8 hours.

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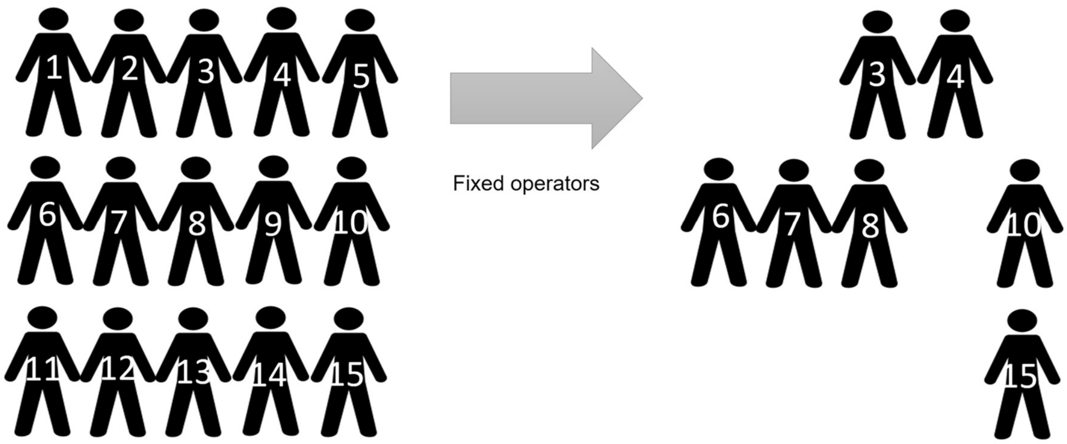

Figure 3. Fixed operators in the workforce.

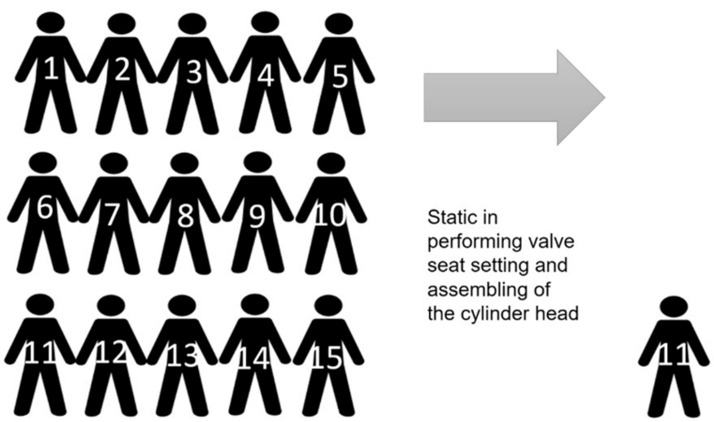

Figure 4. Static valve setter and assembler in the workforce.

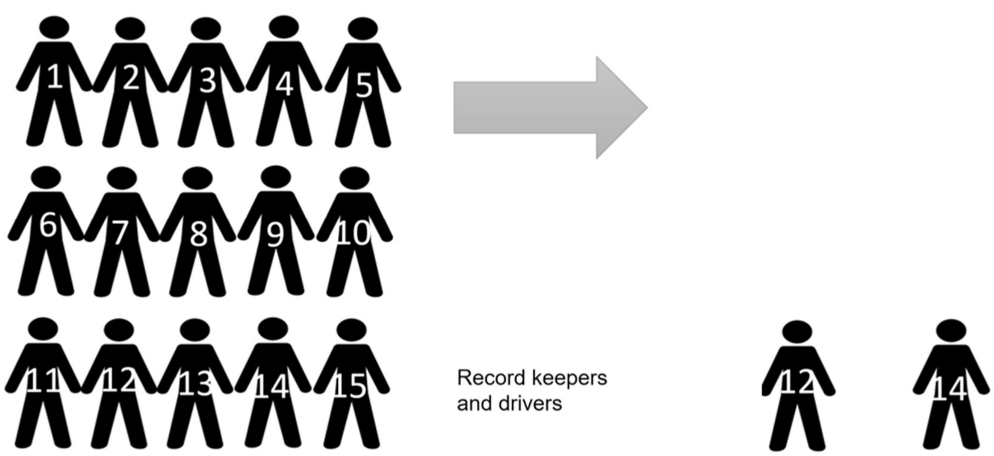

Figure 5. Fixed workers in the workforce

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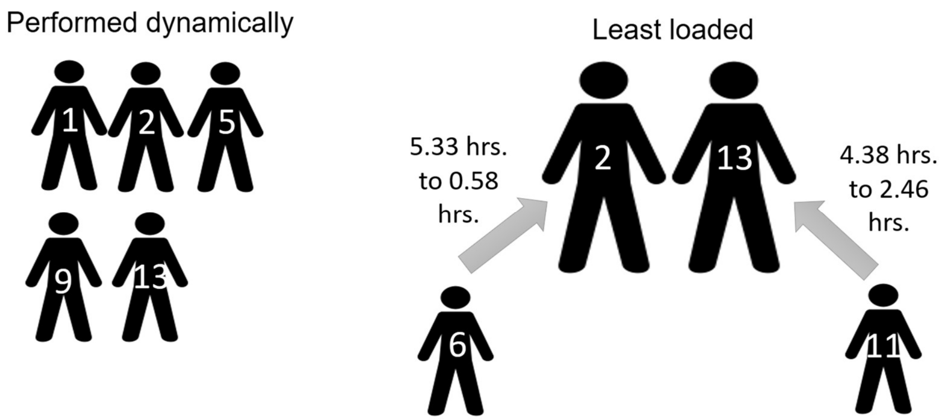

Figure 6. Proposed work distribution

In the proposed distribution, the task of drilling plates of worker six will be given to worker 2 to reduce its idle time from 5.33 hours to 0.58 hours and allow worker 6 to perform additional operations of honing machine. Moreover, worker 13 will assist worker 11 by assembling the parts of the cylinder head to reduce its idle time from 4.38 hours to 2.46 hours.

4.2 Workers operating on the ideal number of machines

Currently, there are no previous studies regarding the use of worker-machine relationship-based strategies. The application of the synchronous servicing approach in this study supposedly produces the ideal number of machines per operator. Initial evaluation of ten operators revealed that Operators 1 and 2 were operating on an ideal number of machines. Both worked on a crankshaft grinding machine, camshaft grinding machine, and arc force electric welding machine with different expected costs. Operator 1 currently with a greater total expected cost of Php498.69/unit with Php17.09/unit differences from the total predicted cost of Operator 2.

Table 3. Traditional set-up with the ideal number of machines

Operators	Machines	Total Expected Cost (Php/unit)			
Operator 1	1 unit of Crankshaft Grinding Machine AMC K1500-M 1 unit of Camshaft Grinding Machine REPCO RT-7 1 unit of Arc Force Electric Welding Machine	n3	498.69	n4	609.57
Operator 2	1 unit of Crankshaft Grinding Machine AMC K1500-M 1 unit of Camshaft Grinding Machine REPCO RT-7 1 unit of Arc Force Electric Welding Machine	n3	481.6	n4	593.21
Operator 3	1 unit of Arc Force Electric Welding Machine 1 units of Master Heavy Duty Lathe Machine I 120h	n2	298.85	n3	350.1
Operator 4	1 unit of Arc Force Electric Welding Machine	n2	269.59	n3	312.95

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Operators	Machines	Total Expected Cost (Php/unit)			
Operator 5	1 units of Master Heavy Duty Lathe Machine I 120h 1 unit of Arc Force Electric Welding Machine 1 units of Lathe Machine C6150	n2	320.98	n3	393.57

Operators 4 and 5 also operated on the ideal number of machines, the arc force electric welding machine and lathe machine. Operator 5 currently has the highest total expected cost of Php320.98/unit, followed by Operator 3 at Php298.85/unit and Operator 4 at Php269.59/unit.

4.3 Workers requiring addition or deduction of machine/s

In case the new number of machines in a set anticipates a more favorable total operation cost, the addition or subtraction of machines is suggested. Only Operator 6 requires one more machine to operate on the ideal number and reduce the current total expected cost of Php10.22/unit. Further increase in the number of machines will only increase the total expected cost of at least Php45.7/unit. Operators 7, 8, 9, and 10 were the workers who would require one less machine to operate on an ideal number and reduce each of their total expected costs.

Table 3. Synchronous servicing on traditional set-up

Operators	Machines	Total Expected Cost (Php/unit)			
Operator 6	1 unit of Cylinder Boring Machine AC170 1 unit of Cylinder Block Boring & Milling Machine CM-1200V 1 unit of Line Boring Machine 1 unit of Arc Force Electric Welding Machine	n4	346.48	*n5*	*336.26*
Operator 7	1 unit of Honing Machine (Stationary) 1 unit of CBN Milling Machine M3000 1 unit of Arc Force Electric Welding Machine 1 unit of Master Heavy Duty Lathe Machine I 120h	n2	157.93	*n3*	*150.66*
Operator 8	1 unit of Surface Grinding Machine 1 unit of CBN Milling Machine M3000 1 unit of Arc Force Electric Welding Machine	n1	184.36	*n2*	*175.77*
Operator 9	1 unit of Valve Seat Cutting Machine 1 unit of Arc Force Electric Welding Machine	*n1*	*174.00*	n2	185.01
Operator 10	1 unit of Tig Welding Machine 1 unit of Arc Force Electric Welding Machine 1 unit of Master Heavy Duty Lathe Machine I 120h	n2	240.84	*n3*	*234.55*

Operator 7 will only require three machines from four machines to reduce the total expected cost to Php150.66/unit. In comparison, Operator 8 will require only two machines to minimize the total expected cost to Php175.77/unit. Operator 9 will only need to operate on one

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machine to reduce the total expected cost of Php11.01/unit. Operator 10 will operate two machines to reduce the total expected cost of Php 30.71/unit.

4.4 Set of machines requiring addition or deduction of workers

Based on the work of Niebel (Freivalds, 2009) random servicing approach applies to the case when there are a group of machines with a possibility of being operated by more than one operator. In this study, only the set of machines being operated by Operator 6 was viable for the possibility of an increase in workers. However, based on the result of random servicing with 0.05 percent of machine downtime, none of the increases in workers will produce any difference in total expected cost since the initial application of the synchronous servicing suggests the addition of machines.

Table 5. Random servicing on traditional set-up

Operators	Machines	Total Expected Cost (Php/unit)
Operator 6	1 unit of Cylinder Boring Machine AC170 1 unit of Cylinder Block Boring & Milling Machine CM-1200V 1 unit of Line Boring Machine	One Operators = 2314.22 Two Operators = 2314.22
Operator 5	Lathe Machine C6150	Two Operators = 7919.64
Operator 3	Master Heavy Duty Lathe Machine I 120h	Three Operators = 7919.64
Operator 9	Master Heavy Duty Lathe Machine I 120h	Four Operators = 7919.64
Operator 10	Master Heavy Duty Lathe Machine I 120h	
Operator 7	Master Heavy Duty Lathe Machine I 120h	

Only the set of lathe machines was viable for the possibility of worker reduction. However, as a result of random servicing, none of the decreases in the worker will cause any changes since 0.27 percent of expected downtime was too negligible due to the regular machine maintenance of each operator.

4.5 Re-assignment of worker and machine

Synchronous servicing reduces or balances the idle time between machine and worker services by producing an ideal number of machines based on the cycle duration of the operation. The ideal number between the two options is decided by determining the lowest total expected cost regarding the operator's rate and machine cost per hour.

Table 6 displays the result validation of the initial application of synchronous servicing by re-conducting the assessment after the re-arrangement based on the proposed machine-worker setup. Operator 6 was currently operating on four machines with a total expected cost of Php346.48/unit and a suggestive expected cost of Php336.26/unit if one more machine is assigned to him. Among the 16 machines, the addition of a surface grinding machine qualified the ideal number and further decreased the expected cost of Php24.83/unit.

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Table 6. Application of synchronous servicing on proposed set-up

Operators	Machines	Total Expected Cost (Php/unit)			
Operator 6	1 unit of Cylinder Boring Machine AC170	n4	331.20	*n5*	*321.65*
	1 unit of Cylinder Block Boring & Milling Machine CM-1200V				
	1 unit of Line Boring Machine				
	1 unit of Arc Force Electric Welding Machine				
	+ 1 unit of Surface Grinding Machine				
Operator 7	1 unit of Honing Machine (Stationary)	n2	166.64	*n3*	*167.63*
	- 1 unit of CBN Milling Machine M3000				
	1 unit of Arc Force Electric Welding Machine				
	1 unit of Master Heavy Duty Lathe Machine I 120h				
Operator 8	**-** 1 unit of Surface Grinding Machine	n1	214.46	*n2*	*247.95*
	1 unit of CBN Milling Machine M3000				
	1 unit of Arc Force Electric Welding Machine				
Operator 9	**-** 1 unit of Valve Seat Cutting Machine	*n1*	*303.03*	n2	303.28
	1 unit of Arc Force Electric Welding Machine				
Operator 10	1 unit of Tig Welding Machine	n2	202.47	*n3*	*260.05*
	1 unit of Arc Force Electric Welding Machine				
	- 1 unit of Master Heavy Duty Lathe Machine I 120h				

In the case of Operator 7, the ideal number of machines from four is three to two, with a savings of Php24.83/unit, while Operator 8 has an ideal number of two machines to save Php8.59/unit. One machine will be reduced from the set of Operator 9 to save an amount of Php11.01/unit, and another machine from the set of Operator 10 to save a cost of Php29.71/unit.

However, on the utilization of reduced numbers of machines, the new expected cost exceeds the initial expected cost. It defies the initial result of synchronous servicing given the available type of machine units. The only viable machine to be removed from Operator 7 was the one unit of CBN milling machine M3000 to yield the ideal number of three machines. Nonetheless, the new expected cost would exceed the initial expected cost of Php29.71/unit. While surface grinding machine of Operator 8 was removed from the set and included in the set of machines of Operator 6, resulting in an increase of Php72.18/unit in the new expected cost. In the case of Operator 9, removing the valve seat cutting machine can be optional since the electric welding machine is a shared operation. However, the new expected cost still exceeds the initial expected cost of Php129.03/unit. For Operator 10, the lathe machine is the most viable machine that can be removed, as stated in random servicing, but there will still be an increase of Php55.21/unit in the new expected cost.

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CONCLUSION

In order to optimize the overall operation on the shop-floor by reducing the idle time of workers both on manual labor and machining, the workload of loaded workers will be distributed to most minor loaded workers. Worker 13 will assist worker 11 by assembling the cylinder head parts to reduce idle time. The task of drilling plates of worker six will be given to worker 2 to reduce its idle time and allow worker 6 to perform additional operations of honing the machine.

In minimizing the cost per machine operation by assigning the suitable operators on the right unit/s of the machine, Operator 6 will require one more machine to his initial number of four machines, and Operators 7, 8, 9, and 10 will require one less machine to operate on an ideal number based on the initial assessment using the synchronous servicing. However, depending on the price of the company's services, the manager or supervisor may implement the changes resulting from the application of synchronous servicing since the yielded total expected cost of each set of machines after the re-assignment is not consistently decreasing. The actual reduction of one machine from Operators 7, 8, 9, and 10 only increased or exceeded the initial total expected cost. The increase in total expected cost may reduce the company's expenses if this will eliminate the present idleness between the machine and its operator and boost the overall production rate of its services. Subtraction of workers was optional in the case of operators of lathe machines since the percentage of expected machine downtime was too small to be significant. The worker's job description as an operator and mechanic was the primary reason for a minute percentage of machine downtime.

LIMITATIONS & FURTHER RESEARCH

The observed limitation of this study includes the less data credibility caused by response bias from the observation awareness, limited unit and variety of machines, and lack of relevant but obsolete data useful in the result verification. Further studies with regards to the methods of engineering will focus on the significant effects upon the installation of the proposed set-up in machine-operator distribution with the objectives of assessing the reduction of idle time and determining the impact of decrease and increase of service/production cost per unit with regards to the prices of services to the overall company's production rate and operating expenses. Overall, the outcome of this study could assist other machine shops or automobile centers in sustainable management, particularly with the nature of the shared operation and similar relevant internal and external business characteristics.

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