

Analysis of Assembling Processes of a Car Cabin for Productivity Management

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Abstract

Most assembling processes of different products in manufacturing industry are conducted manually with use of minor mechanisms and devices on flow lines. Manually conducted assembling processes evaluated by average time of elements of processes on each working station. The purpose of this paper is present a study and analysis and derive mathematical model of productivity of a car assembling processes. The productivity balance calculation based on data obtained from assembling process of a car shows the losses of productivity and their reasons. Mathematical model can find optimal number of assembling stations by criterion of maximum productivity. Discussion on system analysis of a car assembling processes for productivity enhancement is presented. An investigation was based on data obtained from assembling process of a car company.

Keywords

assembling process, productivity, system analysis

1. Introduction

Manufacturers are striving in order to increase productivity and use various techniques and approaches. Industrial managers are looking ways to use all equipments in full capacity and to obtain maximum productivity and efficiency. In reality, in the field of complex system like production lines do not operate at their maximum capacity due to many reasons. Many research and scientists studied dedicated to solve assembling problems for various manufacturing processes. Main efforts of researches were focused on problem to increase productivity with minimum cost of assembling processes. There are fundamental publications in area of assembling processes considering all aspects of manufacturing systems [1-6]. Except this there are many publications in journals and conferences that solving technical, technological and effectiveness problems of assembling processes [7-9]. The problem in manufacturing industry now is due to lack of research papers that dealt with the use of mathematical model based on technology of assembling processes, and reliability of mechanisms and machines that employees use that reflected on productivity of assembling processes. The main contribution of this paper is mathematical modeling of productivity for the assembling process as function of technology, reliability and structure of a line.

2. Methodology of Research

Investigation of productivity in an assembling line environment consists following purposes: to determine potential reserves of productivity in actual production condition; to provide initial parameter for planning a new assembling system based on experience from actual operating arrangement; to determine optimal structure of the assembling line by criterion of maximum productivity. An investigation was carried out on the assembly process of a car cabin for one of production line at company Isuzu Hicom Malaysia SDN BHD. This assembling line contains 18 stations and serviced by same number of employees. The production line has stops. The reason of stops of assembling processes are different by nature of origin. In case of stop of the assembling process at some station all other stations stop.

The research results were recorded according to the methodology. System analysis of assembling processes focuses on aspects: to calculate the provision for the increase in the assembling processes productivity in a particular production condition, and to determine optimal structure of the assembling line by criterion of maximum productivity. Analysis of assembling processes included: the study of assembling process of parts; the construction of all machines and mechanisms involved in assembling process; organization of assembling

line work; managerial aspects. The study and analysis of assembling process are conducted during 24 production shifts and recorded time of all machines and mechanisms work. The records included the time spent in assembling on each station, time spent in idle conditions, methods of repair, number of products produced per shift (Fig. 1) and the length of each cycle. The length of assembling processes and cycle times were calculated in average magnitudes. The bottleneck station had the cycle time $T = 22$ min, which defined the cyclic productivity.

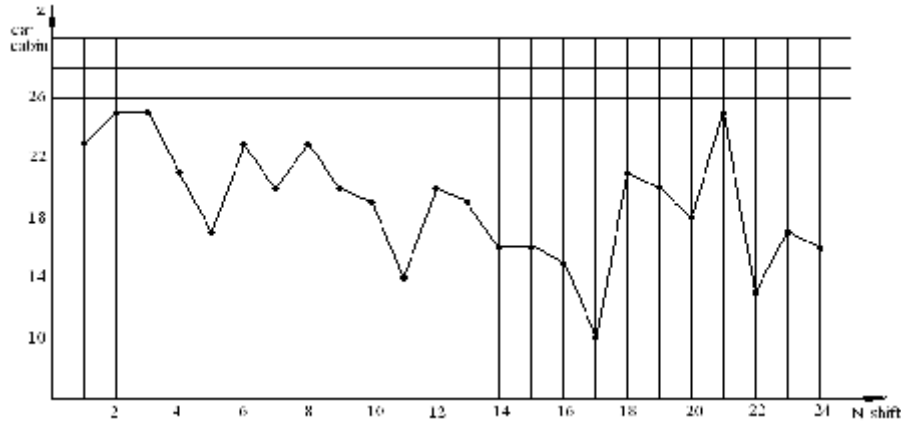


Figure 1. Number of car cabins versus number of shifts

It is used company's statistical data for previous months of work that allowed calculating the average productivity per one shift, which amount is $N_{av} = 20$ car cabins. The deviation δ_i of the average mean cumulative number assembled car cabins per each subsequent shift is calculated by the following formula

$$\delta_i = \frac{\sum_{i=1}^n N_i - N_{av}}{N_{av}} 100\% \quad (1)$$

where N_i is number of the car cabins produced per i shift, other parameter specified above.

The sufficiency of the number of shifts study and research, it is calculated on a basis of the average deviation of productivity that should be less than $\pm 5\%$ of deviation from accepted an average basis. It means ± 1 car cabin, i.e. from $N_{av} = 20$ car cabins. Calculations shows the average mean cumulative number of assembled cars falls in tolerance after 14 -15 shifts of the observation time. Further adding extra shifts of observation will not change the average cumulative number of assembled cars per shift.

The recorded information obtained from the study and analysis of assembling process of the car cabins developed and presented in the Table 1. The total duration of the car cabin assembling time is the sum of assembling times on each station $t_w = 185.64$ min; average time of auxiliary motions on one startion $t_{aux} = 2.5$ min. The cycle time T of the bottleneck station $T = 22.0$ min.

Trustworthiness of the study and calculation results is confirmed by the comparing of time work that obtained practically with theoretically one calculated. Theoretical time of work of the assembling line is $\theta_{w.th} = T \cdot z = 22.0 \text{ min} \cdot 456 = 10032 \text{ min} = 167.2 \text{ hrs}$, where $T = 22.0 \text{ min}$, the number of products $z = 456$ (Table 1). The deviation between practical θ_w and theoretical $\theta_{w.th}$ times calculated by the following formula

$$\delta = \frac{\theta_{w.th} - \theta_w}{\theta_w} * 100\% = \frac{167.2 - 157.2}{157.2} * 100\% = 6.3\%$$

This deviation is acceptable in manufacturing industry that should not exceed 10% and results of study can be considered trustworthy.

3. Analytical Approach

System analysis of production processes presents powerful approach in solving the problem of productivity enhancement. The observation time for the assembling line can be classified as assembling process time and idle time. Assembling process time presents the assembling time and auxiliary time. Assembling time spends on

assembling parts and units. Auxiliary time spends on preparation of assembling process that include deliver parts and units to assembling area, deliver tools, prepare other components for assembling process, etc. Idle time is the time lost because the assembling line does not produce products. All these times of assembling process reflect productivity of the system and can be presented in mathematical expressions.

Table 1. Chronometric analysis of the time observation of the car cabin serial line assembling process

Event	Elements of time distribution from time observation	Duration (hr).
Stops and brakes due to tools and equipment	1. Air pressure low in centralized compressor	1.5
	2. Failure of pneumatic tool at assembly stations	0.5
	3. Conveyor chassis brake dawn	8
	Total stops due to technical reasons θ_t	10
Stops and brakes due to management problem	1. Employees rearranged to working	1.6
	2. Instruction pipe problem from vendor	1.0
	3. Employees rearranged to paint shop	1.7
	Total stops due to management problem θ_m	4.3
Stops and brakes due to logistics	1. The car components cargo not ready from the paint shop	10.9
	2. The plastic part door handle not ready from other shop	1.0
	3. The plastic part cargo not ready from the paint shop	4.0
	Total stops due to logistics θ_l	15.9
Mistaken assembling process	1. Process brake due to pipe leaking	1.6
	2. The wrong component assembled	3.0
	Total stops due to mistaken assembling process θ_{mis}	4.6
Time of total stops	θ_i	34.8
Time of work	$\theta_w = \theta - \theta_i$	157.2
Time of observation	$\theta = 24 \text{ shifts} * 8 \text{ hrs}$	192
Number of car cabins assembled $z = 456$		

The term productivity is formulated as the number of products manufactured per some observation time. On productivity of manufacturing systems influence reliability of machines and mechanisms, managerial and organizational problems, etc. Hence, it is important to have mathematical dependencies of influence all factors on productivity of manufacturing systems. The actual productivity Q_a of any manufacturing system mathematically can be expressed by the following equation

$$Q_a = \frac{z}{\theta} = \frac{z}{\theta_w + \theta_i} = \frac{1}{\frac{\theta_w}{z} + \frac{\theta_i}{z}} = \frac{1}{T + \sum_{k=1}^n t_i} \quad (2)$$

where z - number products manufactured per observation time, $\theta = \theta_w + \theta_i$ - sum of the total work time θ_w for manufacturing z products and the total idle time θ_i that can occur during manufacturing process.

The work time is considered assembling time. Then, obtained ratio of the total work time to the number of product assembled $\theta_w/z = T$ that logically presented the cycle time T of assemble process for one product. The cycle time is sum of assembling time t_w and auxiliary time t_{aux} that expresses the time spend on preparatory motions before and after assembling process, $T = t_w + t_{aux}$. Then, the equation of the cyclic productivity is expressed by the following formula

$$Q_T = \frac{1}{t_w + t_{aux}} = \frac{1}{T} \quad (3)$$

The total idle time θ_i of the assembling line is time losses in observed time and may cause by different reasons like brakes of the conveyor and tools, power drop, defect parts, scheduling problems, etc. Hence, the idle time is the sum of any non productive times relatively to the number of parts assembled during process in production line

formulated by the expression $\theta_i/z = \sum_{k=1}^n t_i$. This expression is a loss time relatively to one product assembled.

Reasons of the idle time can have different nature in origin. In industry is necessary to separate the reasons of the idle time on two groups: technical reasons t_{tech} and organizational or managerial reasons t_{org} . Hence, the time losses relatively to one product assembled is presented by following expression

$$\sum_{k=1}^n t_i = \sum_{l=1}^m t_{tech} + \sum_{p=1}^r t_{org} \quad (4)$$

Finally actual productivity of assembling process after substituting all defined parameters has the equation

$$Q_a = \frac{1}{t_w + t_{aux} + \sum_{l=1}^m t_{tech} + \sum_{p=1}^r t_{org}} = \left(\frac{1}{T}\right) \frac{1}{1 + \left(\sum_{k=1}^n t_i / T\right)} = Q_T A \quad (5)$$

where $A = \frac{1}{1 + \sum_{k=1}^n t_i / T}$ is availability of manufacturing system, other parameters specified above

Ideal productivity of system is when no time losses, then, the ideal productivity expresses by the equation

$$Q_L = 1/t_w \quad (6)$$

To enhance productivity of assembling process, it is used method of segmentation one and time balancing of a production line, which consists from q stations. Then the assembling time on each station is reduced proportionally to the number of stations. Increasing the number of stations lead to increasing of the number of tools for assembling process. These changes mathematically are expressed in Eq. (5) and present by the equation.

$$Q_a = \frac{1}{\frac{t_w}{q} + t_{aux} + \sum_{b=1}^g t_c + q \sum_{d=1}^f t_{st} + \sum_{p=1}^r t_{org}} \quad (7)$$

where t_w/q is average assembling time of one station, $\sum_{b=1}^g t_c$ is time losses due to failures of common mechanisms that do not depend on changes of number of stations (central air compressor, central electrical power supply, etc),

$\sum_{d=1}^f t_{st}$ is time losses due to failures of tools of the station that leads to stops of all q stations.

Practically the auxiliary time t_{aux} and time losses due to managerial or organizational problems do not change with change of the number of stations. Analysis of Eq. (7) express real productivity of the assembling line and shows that this equation has extreme where variable is the number of stations q . The first derivative of Eq. (7) gives optimal number of stations by criterion of maximum productivity of an assembling line and expresses by the equation:

$$q_{opt} = \sqrt{t_w / \sum_{d=1}^f t_{st}} \quad (8)$$

Presented analytical approach of assembling line productivity and results of study enable to calculate main parameters of system that have the following productivity indices:

1. Limit of the assembling serial line productivity (Eq. 6)

$$Q_L = \frac{1}{t_{w.b.st}} = \frac{1}{17.3} = 0.0578 \frac{car}{min} = 3.468 \text{ cars/hr}$$

where $t_{w.b.st} = 17.3$ min is assembling time of the bottleneck station.

2. Cyclic productivity of the assembling serial line

$$Q_T = \frac{1}{T} = \frac{1}{22.0} = 0.0454 \frac{car}{min} = 2.727 \text{ cars/hr}$$

where $T = 22.0$ min is the cycle time of the bottleneck station.

3. Actual productivity of the assembling serial line (Table 1)

$$Q_a = z/\theta = 456/192 = 2.375 \text{ cars/hr}$$

4. Productivity losses of the assembling line due to defined reasons ΔQ_i calculated on a basis of Table 1. Cyclic productivity losses due to auxiliary time calculated by formula
 $\Delta Q_1 = L - Q_T = 3.468 - 2.727 = 0.741$ cars/hr
5. Other productivity losses of the assembling line calculated by the ratios of idle times as $\theta_c:\theta_{mis}:\theta_m:\theta_l = 10:4.6:4.3:15.9$ (Table 1). $\Delta Q_i = Q_T - Q_a = 2.727 - 2.375 = 0.352$ car/hr; $\Delta Q_2 = 0.101$ car/hr, $\Delta Q_3 = 0.046$ car/hr, $\Delta Q_4 = 0.043$ car/hr, $\Delta Q_5 = 0.161$ car/hr.
6. Availability of the car cabins assembling serial line is:

$$A = \frac{1}{1 + \sum_{k=1}^n t_i / T} = \frac{1}{1 + \frac{\theta_i}{zT}} = \frac{1}{1 + \frac{\theta_i}{z \left(\frac{t_w}{q} + t_{aux} \right)}} = \frac{1}{1 + \frac{34.8 * 60}{456 * 22.0}} = 0.827$$

where $\theta_i = 34.8 * 60$ min (Table 1), other parameters specified above.

All calculated parameters of the assembling serial line productivity are presented in Fig. 2

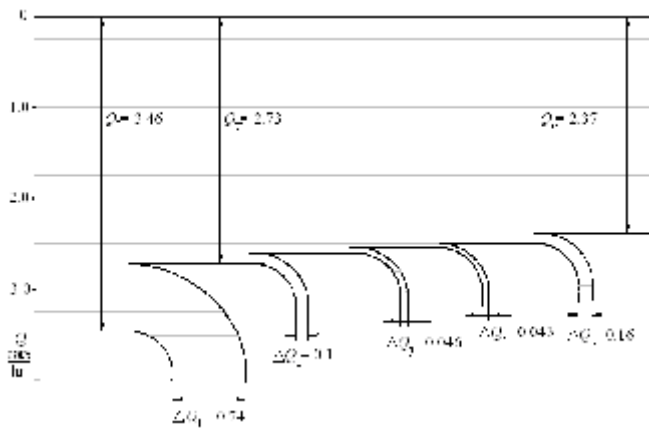


Figure 2. Productivity parameters of the car cabin assembling line and productivity losses.

The assembling line productivity losses shows major loss is due auxiliary time, and less losses due to other reasons. The efficient assembling line can produce 3.46 car cabins per hour but due to losses, it can produce only 2.37 car cabins per hour. All these losses are the sources of increasing productivity of the assembled line. Mathematical dependency of the productivity of assembling line as function of number of stations, technological and technical parameters one, Eq. (8) enables to analyze all factors that influence on productivity. Difference between mathematical model and real one explained by reasons that balancing is conducted unevenly; initial data collected with deviations, etc. However, analytical approach enables theoretically solve many technical problems and predict real output of systems with minor corrections. The results of study of the car cabins assembling line used for calculation and graphical presentation of its productivity. The initial data of the assembling line is calculated above that are follow: $t_w = 185.64$ min, $t_{aux} = 2.5$ min is average of auxiliary time,

$$\sum_{b=1}^g t_c = \frac{\theta_c}{z} = \frac{9.5 * 60}{456} = 1.25 \text{ min is the time loss due to technical reasons of common mechanisms,}$$

$$\sum_{d=1}^f t_{st} = \frac{\theta_{st}}{z} = \frac{(4.6 + 0.5) * 60}{456} = 0.671 \text{ min is the time loss due to technical reasons at one station,}$$

$$\sum_{p=1}^r t_{org} = \frac{\theta_m + \theta_l}{z} = \frac{(4.3 + 15.9) * 60}{456} = 2.657 \text{ min is the time loss due to managerial and logistics problems.}$$

After substituting into Eq. (7) and transformations the productivity rate of the assembling line has the expression

$$Q_a = \frac{1}{\frac{t_w}{q} + t_{aux} + \sum_{b=1}^g t_c + q \sum_{d=1}^f t_{st} + \sum_{p=1}^r t_{org}} = \frac{1}{\frac{185.64}{q} + 0.671q + 6.4} \quad (9)$$

Analysis of Eq. (9) shows that productivity of the assembling line grows at the beginning of increasing the number of stations and going down after some number of stations, which gives maximum productivity. Optimal number of stations of the assembling line that gives maximum productivity is calculated by Eq. (8).

$$q_{opt} = \sqrt{t_w / \sum_{d=1}^f t_{st}} = \sqrt{\frac{185.64}{0.671}} = 17$$

The theoretical optimal number of stations of the assembling line ($q_{opt} = 17$) is close to actual number of station ($q = 18$) and confirms that company solved the structure of the assembling line by the best solution. Also, it means that theoretical approach of the car assembling line productivity is correct and can be used for calculation of a productivity of the assembling lines with minor correction.

4. Results and Discussion

The study and investigation of the assembling line process of a car cabin presented results of the line productivity. The availability of the assembling line is 0.8 that is normal data in manufacturing industry. Productivity diagram of the car cabin assembling line shows losses, type and reason one where most inefficiencies in auxiliary time. The productivity can be improved by the time balancing assembly stations to reduce bottleneck of the production system. Engineers have to decrease the auxiliary time that takes 21% of the productivity loss by rearranging auxiliary motions, increase the reliability of air compressor, conveyor and pneumatic tools and other mechanisms, to reduce idle time that takes 5.5% of the productivity loss. Managers should find a solution to reduce idle time that takes 4.6% of the productivity loss. Analytical solutions of the assembling line productivity confirmed by practical results of study and can be used for practical application at project stage of design new assembling lines.

5. Conclusion

The new mathematical and practical approach of study assembling lines presented can be used particularly by manufacturers in solving of enhancement productivity of systems. The proposed system analysis of assembling processes can be applied to any kind of technological processes. The main findings from this study include the main losses in the car cabin assembling process that fall to auxiliary motions, reliability of air compressor, conveyor, pneumatic tools and not perfect managerial activity that takes in general 31% of productivity loss. These productivity losses should be reduced by improvement of manufacturing process to increase output the car cabin assembling line. The result of analytical approach of the productivity of the assembling line are equations of productivity as function of technological process, reliability of machines and mechanisms, structure of assembling line and management. All findings are useful and can be applied in manufacturing industries to improve efficiency of production processes.

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