RESEARCH ARTICLE

Minimization of Total Variable Cost through Determination of Batch Transfer Size at *m* Serial CNC-Machining Centers [version 1; peer review: awaiting peer review]

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Abstract

Background: In a batch production series consisting of several process stages for discrete products, the determination of the transfer batch size greatly affects the batch waiting time. For production using a Computer Numerical Control (CNC)-machining center, several process stages can be carried out on one machine with quick setup. The use of a single machine for all stages of the process certainly does not require transfer to the next machine. Thus, there are no material handling costs. However, the use of a single machine will result in longer batch waiting times as the production batch size increases. An increase in the batch waiting time will result in an increase in work-in-process (WIP) inventory cost. This research was conducted to reduce the total variable cost consisting of WIP inventory cost and material handling cost.

Methods: This research was conducted in two steps. The first step is to divide the process stages, I into m serial CNC machining centers, where in this study $I=m$. The second step is to determine the same size of transfer batch, Q_{ij} for a certain number of transfers, J that produces the minimum total variable cost.

Results: The results showed that J=5 resulted in a total variable cost of Rp. 146,800.00, while J=10 resulted in a total variable cost of Rp. 178,900.00.

Conclusion: In conclusion, the total variable cost decreases if the size of transfer batch is reduced to a certain amount and will increase again along with the reduction in the size of transfer batch.

Keywords

CNC-Machining Center, batch production, production batch, WIP inventory, transfer batch, total variable cost

Open Peer Review

Approval Status *AWAITING PEER REVIEW*

Any reports and responses or comments on the article can be found at the end of the article.

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1. Introduction

In batch production, a machine is assigned to complete a job in a large batch size before moving on to complete the next job. As the batch size increases, the batch waiting time will increase. If a job requires multiple processes, the batch waiting time will be longer because switching from one process to the next requires setup. The switch from one process to the next is done on one machine or it can be switched to the next machine. A Computer Numerical Control (CNC)-machining center can perform multiple processes on one machine.

The advantage of a CNC-machining center is that it can perform several processes singly with quick setup. The ability to perform multiple process stages in a CNC-machining center is not found on conventional machines. In general, the use of conventional machines in a series of batch production requires a transfer process to another machine because one machine cannot perform all stages of the process. Advantages of the CNC-machining center resulted in the tendency to use a single machine to carry out multiple processes of a product. This is understandable because all stages of the process can be completed on one machine so there is no need for a transfer process, setup can be done quickly. Single use result in the batch waiting time to be long which has implications for increasing work in process (WIP) inventory. If there is more than one CNC-machining center, single use can be avoided by dividing the process stages into available machines in series (sequentially). Using *m* machines to complete a batch, requires transfer between machines. The use of *m* machines allows two or more process stages to be carried out concurrently. The selection of the transfer batch size is important because it affects the batch waiting time and the number of transfers. On one side, small batch size can reduce batch waiting time. On the other hand, small batch size can increase the transfer frequency which of course increases material handling costs. The use of serial machines will make it possible to determine the size of the transfer batch that can minimize the total variable cost that consisting of WIP inventory costs and material handling costs.

Research on batch production has been carried out by several authors. Sukoyo *et al.*[1] conducted research on batch scheduling with the performance goal is the actual flow time. Research on batch scheduling to minimize makespan was conducted by Ozturk *et al.*[2] Research with the aim of minimizing total weighted work delays in real-world single batch processing machine (SBPM) scheduling with fuzzy due dates, was conducted by Niroom *et al.*[3] Research aimed at minimizing makespan on a single processing machine was carried out by Li and Wang.[4] Research with the aim of minimizing the number of setups required by independent job orders grouped into several classes based on similarity in style was carried out by Yimer and Demirli.[5] Mathematical modeling of batch scheduling problems to minimize start and delay was carried out by Ogun and Uslu.[6] Muhammad, *et al.*[7] conducted research about batch production at m serial CNC-machining center to minimizing WIP inventory cost. This study is a development of a study that has been done by Muhammad, *et al.*[7] This study proposes to schedule *I* stage to *m* machines and then determine the optimal Q_{ij}, which minimizes the total variable cost.

2. Methods

In a series of stages of batch production, number of stages *I* can be assigned to *m* serial machines. For example, I=3 can be assigned to m=3. Initially, batch of 50 units ($Q = Q_{ij}$= 50) and requires I=3 carried out on m=1. If t_1 is 48 minutes/unit, (t_2) is 25 minutes/unit, t_3 is 23 minutes/unit, S_1 is 35 minutes/batch, S_2 is 5 minutes/batch, S_3 is 15 minutes/batch, then the results of scheduling are illustrated in Figure 1.

Next, J = 5, I=3 is scheduled on m=3 where one machine for one stage. This scheduling requires 5 transfers each from Machine 1 to Machine 2 and from Machine 2 to Machine 3. For example, using Q_{ij}=10 units, then results of scheduling for J=5, m=3 is illustrated in Figure 2.

In Figure 1, the waiting time for each unit in the batch in Stage 1 is obtained from the size of the production batch multiplied by the processing time per unit then added with the setup time minus the processing time per unit, which

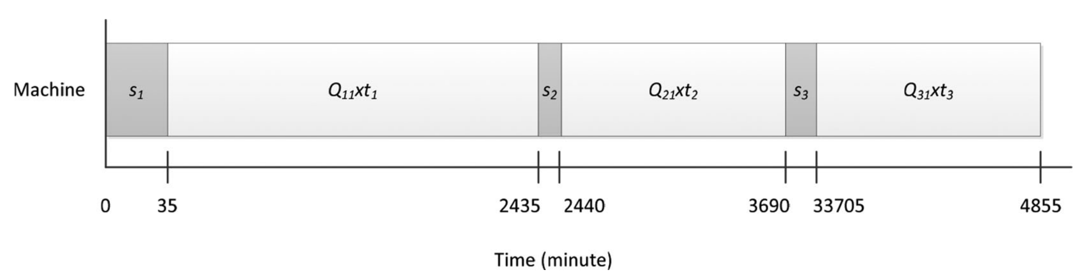

Figure 1. Illustration of schedule for Q_{ij}=50 on m=1.

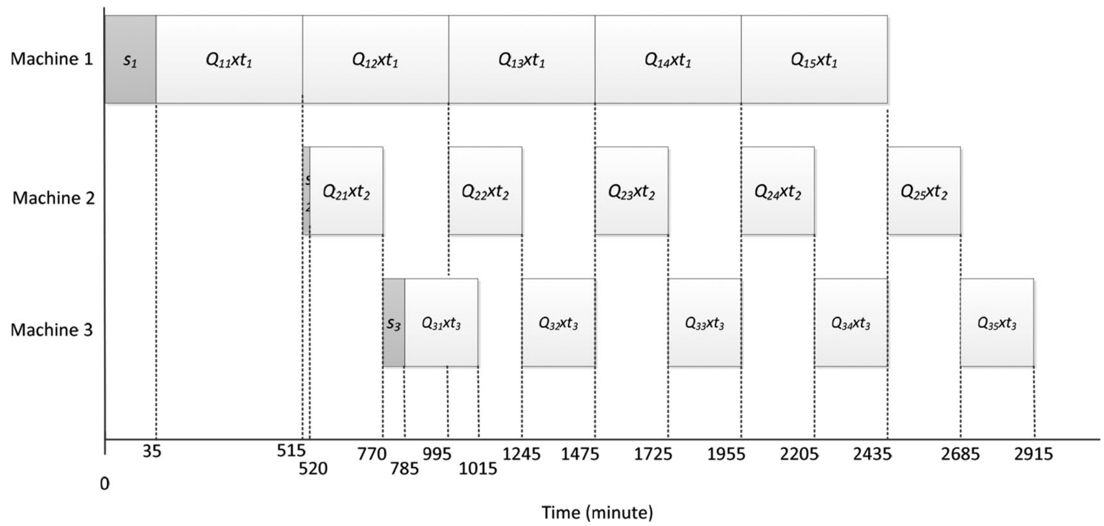

Figure 2. Illustration of schedule for *J*=5, Q_{ij}=10 on *m*=3.

is 50 units × 48 minutes/unit + 35 minutes – 48 minutes = 2,387 minutes. Therefore, the batch waiting time in Stage 1 is 50 units × 2,387 minutes per unit = 119,350 minutes. In Figure 2, the waiting time for each unit in the batch in Stage 1 is 10 units × 48 minutes/unit + 35 minutes – 48 minutes = 467 minutes. Therefore, the batch waiting time in Stage 1 is 10 units × 457 minutes per unit = 4,570 minutes. However, the number of transfers from the schedule in Figure 2 is 10 times, more than 0 times from the schedule in Figure 1.

The following notation is used for discussion of determining the transfer batch size that minimizes the total variable cost:

$$Q: \text{size of production batch}$$

$$J: \text{number of transfer}, j \epsilon J; j = 1, 2, 3, \ldots, Q$$

$$I: \text{number of stage}, i \epsilon I$$

$$m: \text{number of machine}; m = 1, 2, 3, \ldots I$$

$$S_i: \text{set up time}\left(\frac{\text{minute}}{\text{batch}}\right)\text{of stage } i$$

$$t_i: \text{processing time}\left(\frac{\text{minute}}{\text{unit}}\right)\text{of stage } i$$

$$Q_{ij}: \textit{size of } \text{transfer batch } j \text{ stage } i$$

$$F_{ij}: \text{flowtime}\left(\frac{\text{minute}}{\text{unit}}\right)\text{of batch } j \text{ until stage } i$$

$$w_{ij}: \text{waiting time}\left(\frac{\text{minute}}{\text{unit}}\right)\text{of each unit in batch } j \text{ until stage } i$$

$$W_{ij}: \text{waiting time}\left(\frac{\text{minute}}{\text{batch}}\right)\text{batch } j \text{ until stage } i$$

$$W_i: \text{total waiting time (minute) until stage } i$$

$$H: \text{holding cost}\left(\frac{\text{Rp}}{\text{minute}}\right)$$

$$C_{WIP}: \text{work in process inventory cost}(\text{Rp})$$

$$C_{TR}: \text{transfer cost}\left(\frac{\text{Rp}}{\text{transfer}}\right)$$

$$C_{MH}: \text{material handling cost}\ (\text{Rp})$$

$$TVC: \text{total variable cost}\ (\text{Rp})$$

$$F_{ij} = Q_{ij} \times t_i + S_i + \max\left[F_{i-1j}; F_{ij-1}\right] \quad (1)$$

$$w_{ij} = F_{ij} - t_i \quad (2)$$

$$W_{ij} = \sum\nolimits_{j=1}^{J} Q_{ij} \times w_{ij} \quad (3)$$

$$W_i = \sum\nolimits_{i=1}^{I} W_{ij} \quad (4)$$

$$C_{WIP} = W_i \times H \quad (5)$$

$$C_{MH} = J\, x\, C_{TR} \quad (6)$$

$$TVC = C_{WIP} + C_{MH} \quad (7)$$

The number of transfers is determined by the size of the transfer batch. The number of transfers will be more if the size of the transfer batch is smaller. On the other hand, the number of transfers will be less if the size of the transfer batch is larger. Waiting time is also influenced by the size of the number of transfers. Waiting time increases if the number of transfers is reduced and vice versa. That is, WIP inventory costs are caused by waiting time, while material handling costs are caused by the number of transfers. The sum of these two costs is the total variable cost.

3. Results and discussion

In this section, we begin by scheduling a production batch size of 50 units (Q=50) which are produced through three process stages (I=3) on one machine. Next, I=3 is assigned to three machines (m-3) serially, where each machine performs one process stage in sequence. The use of three machines serially require transfer from Machine 1 to Machine 2 and continued from Machine 2 to Machine 3. In this scheduling, a batch transfer size of 10 units is selected so that the number of transfers is 5 times (J=5) from Machine 1 to Machine 2. and from Machine 2 to Machine 3. In comparison, a transfer batch size of 5 units (J=10) was also selected. Finally, the total variable cost is calculated for I=3 performed on one machine, I=3 and J=5 on 3 machines, I=3 and J=10 on three machines.

Table 1 represents the scheduling results of $I = 3$, $m = 1$. Next, Table 2 to Table 4 represent the scheduling results of J=5, I=3, m=3.

Scheduling in Table 1 shows the results W_1 is 544,200 minutes. Thus, the results WIP inventory cost, $C_{WIP} = 544,200 \text{ minutes}\, x\, \text{Rp}\, 1.00 \text{ per minute} = \text{Rp}\, 544,200.00$, material handling cost, $C_{MH} = 0\, x\, \text{Rp}\, 5,000.00 = \text{Rp}\, 0.00$, $TVC = \text{Rp}\, 544,200.00 + \text{Rp}\, 0.00 = \text{Rp}\, 544,200.00$.

Scheduling in Table 2 shows the result of total waiting time until Stage 1, W_1 is 71,350 minutes. Total waiting time, W_1 is obtained from the sum of W_{11}, W_{12}, W_{13}, W_{14}, and W_{15}.

Scheduling in Table 3 shows the result of total waiting time until Stage 2, W_2 is 85,050 minutes. Total waiting time, W_2 is obtained from the sum of W_{21}, W_{22}, W_{23}, W_{24}, and W_{25}.

Table 1. **Scheduling results of *I*=3, *m*=1.**

I=3	1	2	3
Q (unit)	50	50	50
S_i (minute/batch)	35	5	15
t_i (minute/unit)	48	25	23
F_{ij} (minute/unit)	2,435	3,690	4,855
w_{ij} (minute/unit)	2,387	3,665	4,832
W_{ij} (minute/batch)	119,350	183,250	241,600
W_i (minute)	544,200		

Table 2. **Scheduling results of *i*=1, *J*=5 on Machine 1.**

J=5	1	2	3	4	5
Q_{1j} (unit)	10	10	10	10	10
S_i (minute/batch)	35	0	0	0	0
t_i (minute/unit)	48	48	48	48	48
F_{ij} (minute/unit)	515	995	1,475	1,955	2,435
w_{ij} (minute/unit)	467	947	1,427	1,907	2,387
W_{ij} (minute/batch)	4,670	9,470	14,270	19,070	23,870
W_i (minute)	71,350				

Table 3. **Results of scheduling for *i*=2, *J*=5 on Machine 2.**

J=5	1	2	3	4	5
Q_{1j} (unit)	10	10	10	10	10
S_i (minute/batch)	5	0	0	0	0
t_i (minute/unit)	25	25	25	25	25
F_{ij} (minute/unit)	770	1,245	1,725	2,205	2,685
w_{ij} (minute/unit)	745	1,220	1,700	2,180	2,660
W_{ij} (minute/batch)	7,450	12,200	17,000	21,800	26,600
W_i (minute)	85,050				

Table 4. **Results of scheduling for *i*=3, *J*=5 on Machine 3.**

J=5	1	2	3	4	5
Q_{1j} (unit)	10	10	10	10	10
S_i (minute/batch)	15	0	0	0	0
t_i (minute/unit)	23	23	23	23	23
F_{ij} (minute/unit)	1,015	1,475	1,955	2,435	2,915
w_{ij} (minute/unit)	992	1,452	1,932	2,412	2,892
W_{ij} (minute/batch)	9,920	14,520	19,320	24,120	28,920
W_i (minute)	96,800				

Table 4 shows the results of Stage 3 scheduling ($i = 3$). For example, for Batch 5, from Eq. (1) obtained F_{35} = 10x23 +0 + *max* [2,685; 2,435] = 2,915 minutes. From Eq. (2) obtained W_{35} = 2,915-23 = 2,892 minutes. The waiting time of batch 5, Q_{35}xW_{35}, is 28,920 minutes. From Eq. (3) obtained total waiting time until Stage 3, W_3 is 96,800 minutes. Thus, the results $C_{WIP} = 96,800\,\text{minutes}\,x\,\text{Rp}\,1.00\,\text{per minut} = \text{Rp}\,96,800.00$, $C_{MH} = (5+5)\,x\,\text{Rp}\,5,000.00 = \text{Rp}\,50,000.00$, $TVC = \text{Rp}\,96,800.00 + \text{Rp}\,50,000.00 = \text{Rp}\,146,800.00$.

If the transfer batch size is 5 units (J=10), then W_3 is 78,900 minutes. Thus, the results $C_{WIP} = 78,900\,\text{minutes}\,x\,\text{Rp}\,1.00\,\text{per minut} = \text{Rp}\,78,900.00$, $C_{MH} = (10+10)\,x\,\text{Rp}\,5,000.00 = \text{Rp}\,100,000.00$, $TVC = \text{Rp}\,78,900.00 + \text{Rp}\,100,000.00 = \text{Rp}\,178,900.00$.

From this case, it is found that the reduction in the transfer batch size causes the total variable cost to decrease and will increase again as the transfer batch size decreases. For example, when the transfer batch size is 10 units (J=5), the total variable cost is Rp 146,800.00, but when the batch transfer size is 5 units (J=10), the total variable cost is Rp 178,900.00.

4. Conclusion

Assignment of several stages of the process, I to m CNC-machining centers will reduce WIP inventory costs compared to using one machine for I. Using m machines requires transfer to the next machine which results in material handling costs. There is a tradeoff between WIP inventory costs and material handling costs. Therefore, in this study, the minimum total variable cost is used as a criterion in determining the size of the transfer batch, Q_{ij} which results in the number of transfers, J. From the results and discussion, it is obtained that J=5 produces a total variable cost of Rp. 146,800.00, smaller compared to J=10 which results in a total variable cost of Rp. 178.900.00.

However, this research is still limited to the case of the same number of process stages as the number of machines (I=m), not yet discussing the $I \neq m$ case. If the research is extended to the $I \neq m$ case, then what must be considered as a decision variable is not only the number of transfers, J but also the number of process stages, I to be assigned to a particular machine. Furthermore, there is a situation where the size of transfer batch, Q_{ij} is not always constant for the same J. If there is a situation like this, then the determination of Q_{ij} will affect J which of course has implications for the total variable cost.

Data availability

Underlying data

Figshare. Data Artikel Minimization of Total.xlsb. DOI: https://doi.org/10.6084/m9.figshare.19430618[8]

This project contains the following underlying data:

- The data used to calculate the waiting time and the number of transfers at the minimum m CNC-Machining Centers that minimize the Total Varable Cost.

- The data consists of: Production batch size, setup time, processing time, transfer batch size.

Competing interests

No competing interests were disclosed.

Grant information

Universitas Islam Bandung.

References

1. Sukoyo, Samadhi TMAA, Iskandar BP, *et al.*: **Model penjadwalan batch multi item dengan dependent processing time.** *J. Teknik Industri.* 2010; **12**(2): 69–80.

2. Ozturk O, Espinouse ML, Mascolo MD, *et al.*: **Makespan minimization on parallel batch processing machines with non-identical job sizes and release dates.** *Int. J. Prod. Res.* 2012; **50**(20): 6022–6035. (Taylor & Francis).

3. Niroomand S, Mahmoodirad A, Zavardehi SMA: **Single batch-processing machine scheduling problem with fuzzy due-date: mathematical model and metaheuristic approach.** *Handbook of Research on Modern Optimization Algorithms and Applications in Engineering and Economics.* USA: Engineering Science Reference; 2016; pp 751–769 chapter 28.

4. Li XL, Wang Y: **Scheduling batch processing machine using max-min ant system algorithm improved by a local search method.** *Math. Probl. Eng.* 2016; **2018**: 1–10.
Publisher Full Text

5. Yimer AD, Demirli K: **Fuzzy scheduling of job orders in a two-stage flowshop with batch processing machines.** *Int. J. Approx. Reason.* 2009; **50**: 117–137.
Publisher Full Text

6. Ogun B, Uslu CA: **Mathematical models for a batch scheduling problem to minimize earliness and tardiness.** *J. Ind. Eng. Manag.* 2018; **11**(3): 390–405.
Publisher Full Text

7. Muhammad CR, Nu'man AH, Shofia N: **Minimization of WIP inventory cost at CNC-machining centers through assignment of m serial machines anf transfer batch size reduction.** *IOP Conf. Series: Materials Science and Engineering.* 2019; **830**: 032096.
Publisher Full Text

8. Muhammad CR, Nu'man AH: **Data Artikel Minimization of Total. xlsb. figshare.** *Dataset.* 2022.
Publisher Full Text