Selection of Different Seru Production Systems in Multi-Period Environments

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Abstract

Seru production systems are popular in electronics industry in Japan and many companies successfully implemented these concepts. Several companies converted their long assembly lines to shorter and smaller production units. Seru is more closely related to assembly systems and even though several works reported comparing it to manufacturing cells. We can call assembly cells to distinguish them from manufacturing cells. This study focuses on yatai (single worker) and divisional seru (similar to assembly line balancing except they are limited to 2 workers or 3 workers). Three- phase solution methodology is proposed and mathematical models are proposed to determine hybrid yatai-divisional seru systems to minimize the total number of workers. We experiment with different data sets in a multi-product multi-period environment. The results show that the total number of workers is reduced by varying worker assignment to products in different periods. On the other hand, if uniform production is required then number of workers increases. We believe that these models will the basis to further develop studies in this area.

Keywords
Seru, Assembly Line, Mathematical Modeling, Worker Allocation to Products, Multiple Periods

1. Introduction

Seru is a Japanese word which means cell (Zhang et. al., 2017). It is a production system developed in Japan in 1992 (Sakazume, 2005). It is well known in Asia but not much known elsewhere. Japanese electronics companies for example Canon, Panasonic, Sony, Fujitsu NEC and Hitachi are practicing Seru (Iwamuro, 2004). Many practitioners of Seru believe that this production system works better when the demand volume is low but the variety is high (Villa et. al., 2013). The basis of Seru is that 'One worker, or a small number of workers, carries all the operations in an assembly line' (Zhang et. al., 2017). A Seru is dedicated to one or several similar product types which have one or may be 2-3 workers. These workers are multi-skilled and they can perform all of the operations that are required to produce the finished product. In other words, long assembly lines are broken into several small complete lines where simple equipment are used. According to Zhang et. al., (2017) and Yu et al. (2013) Seru has several advantages over classical cellular manufacturing system such as it is highly flexible for high variety low volume products. It can reduce the workspace, workforce, WIP inventories and lead time but also it provides improved quality and most importantly it leads to very high satisfaction of workers. Jonsson et. al., (2004) reported that Seru also results in better ergonomics of work environment. According to Liu et al. (2014), Seru combines the advantages of job shop, mass production and sustainable manufacturing. From literature it is found that Seru has three different classifications namely divisional Seru, rotating Seru and yatai.

1.1 Divisional Seru
According to Yu et al. (2012), a divisional seru is "a short line staffed with several partially cross-trained workers where the tasks are divided into different sections and each section is operated by one or more worker" Yu et al. (2012). Divisional Seru is the modification of conveyor assembly line where a worker performs more task than in conveyor assembly line as shown in Figure 1. In a divisional Seru, workers are multi-skilled compared to the conventional assembly line.

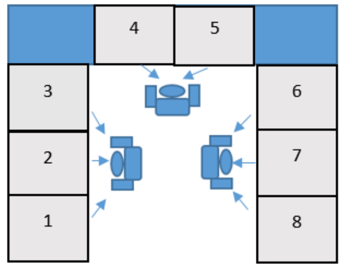

Figure 1. A Divisional Seru

1.2 Rotating Seru

In rotating Seru there are multiple multi-skilled workers who move from one workstation to another to perform all the tasks based on a fixed order (Figure 2). In this type of Seru workers move from one workstation to another with the product. One worker is responsible for assembling an entire product from beginning to the end. Generally, this type of Seru has a U-shaped structure (Yu et al. 2013).

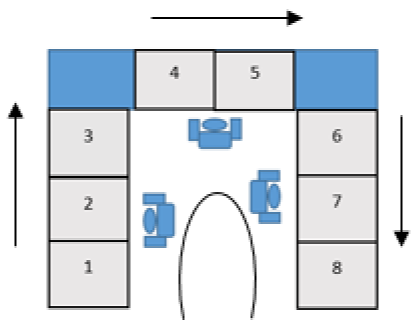

Figure 2. A Rotating Seru

1.3 Yatai

Yatai is the special form of rotating Seru where there is only one worker and he/she doesn't need to rotate from workstation to workstation rather all the equipment are accessible. Generally, a Yatai owner is the one who carry out all the operations from operational to managerial (Yu et al. 2013). Figure 3 shows three different yatais.

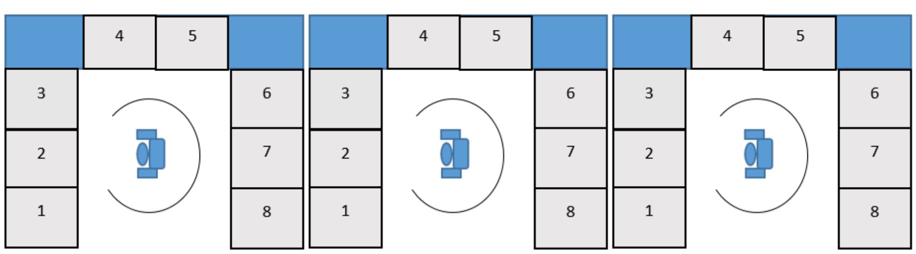

Figure 3. Three different Yatais from a rotating Seru

1.4 Objective

In this paper, we are introducing mathematical models to determine what kind of Seru production systems will be needed to meet the demand of multiple products in a multi-period environment. The study is limited to Yatais and 2-worker and 3-worker divisional Seru production systems. This problem is addressed in a multi-period environment.

The performance measure is to minimize the total number of workers needed over the planning horizon. We are not aware any study that addresses this issue in the literature.

2. Literature Review

Several studies focused on conversion from assembly lines to seru production systems where worker training is needed to obtain multi-skilled workers. Liu et al. (2013) studied the problem of training the workers to minimize the total training cost and balance the total processing time in each seru. The authors developed a multi-objective mathematical model where the two objectives are to minimize task-to-worker training cost and optimal assignment of workers-to-seru. They considered divisional seru and yatais. Yu et al. (2013) discussed the conversion of assembly line into Seru or pure cell system. Their objectives are to reduce worker for a converted cell and to increase productivity. In their study, the authors considered only rotating Seru and yatai. Kaku et al. (2008) studied the conversion of assembly line to cellular manufacturing strategy considering human-task-related parameters. They considered the number of possible tasks that can be added, skill level and workers cross training while developed three distinct models. Kaku et al. (2009) presented a study where they defined and approached a line-cell conversion problem for a single product type. They reported three achievements so far in their study which are number of cells to be formatted, number of workers required to be assigned in each cell and reduction of workers when the assembly line is converted into cells. Yang et al. (2016) studied the problem of line cell conversion considering two different objectives such as total throughput time (TTPT) and total labor hour (THL). For this multi-objective problem they first attempted mathematical model and later switched to Genetic Algorithm (GA) since the problem became NP-hard. Yu et al. (2017a) presented a study where they considered the conversion of a hybrid system consists of short line and Seru. Claiming that a hybrid system of seru and short line is more pragmatic than a pure seru system (some equipment might be expensive and costly to purchase multiple of those), they developed models for conversion of line-hybrid Seru systems, Yu et al. (2017b) presented a study where their objective is to reduce number of workers without increasing makespan for a line-Seru conversion case. Ying & Tsai (2017) conducted a study where their objective is to minimize cost of training for worker so that the workers can become multi-skilled and Seru can be implemented using those multi-skilled workers.

Some other researchers focused on designing Seru production systems in terms of number Serus and worker assignment to Serus. Liu et al. (2012) conducted a study where they proposed a comprehensive mathematical model. They considered several assumptions while designing the mathematical model. Finally, they checked the model using real life data from an industry and compared the result with the model of Kaku (2008). The authors claimed that the proposed model is better than that of Kaku's model.

Liu et al. (2014) suggested a comprehensive guideline about implementing Seru. The authors suggested some basic steps that should be followed if someone is implementing Seru for the first time. The steps are identifying product design and process requirement, Selection of seru, material delivery method, production balancing, cross training of workers and evaluation of Seru production System. Yu et al. (2016) conducted a study reflecting the complexity of converting line into Seru in terms of scheduling. They considered ten different scheduling rules to show the impact of commonly used scheduling rules on the performance of line-seru conversion. They also considered two performance measure namely Total Throughput Time (TTPT) and Total Labor Hour (TLH) to develop a bi-objective model.

Abdullah et al. (2019) focused on skills in both assembly lines and seru systems. Aboelfotoh et al. (2019) analyzed both Assembly Lines and Seru systems to determine which one to choose under varying conditions. Suer et al. considered product life cycle stages and skills to decide when to use assembly lines and when to use seru systems.

Stecke et al. (2012) presented a study where the authors discussed the evolution of Seru from Toyota Production System (TPS). According to authors TPS is not fit for a volatile market where the product has a very short life cycle. The authors also discuss how Seru is better than TPS in dealing with volatile product type.

3. The General Methodology Used

The methodology used in this paper consists of three phases as discussed below:

Phase 1. Compute Cycle Time (CT) for Yatai Production System
This phase involves rather simpler calculations.

Phase 2. Perform assembly line balancing for Divisional Seru System

Mathematical Model is run for each product for alternative divisional Seru production system designs.

Phase 3: Design multi-product assembly system
A mathematical model is developed for optimal allocation of workers to multiple products.

4. Detailed Discussion of the Methodology

In this section, the methodology is discussed in detail.

4.1 Phase I. Computing Cycle Time for Yatai Production System

In this paper, two different seru productions systems will be evaluated; 1) Yatai System ii) Divisional Seru System. As mentioned earlier, in Yatai system, one worker carries out all assembly tasks. On the other hand, in divisional seru system, tasks are divided into a small number of workers, particularly two or three workers. In the following sections, the methodologies used are described.

In Yatai type Seru production systems, the total processing time is easily computed by simply adding processing times of all operations (equation 1) where t_i is the processing time of operation *i*, *n* is number of operations, CT_{yatai} is the cycle time for Yatai system. This information can be used to determine production rate per yatai, PR_{yatai}, unit per period as shown in equation 2 where *CAP* is the capacity available per period and PR_{yatai} production rate per Yatai unit per period.

$$CT_{yatai} = \sum_{i=1}^{n} t_i \quad (1)$$
$$PR_{yatai} = \frac{CAP}{CT_{yatai}} \quad (2)$$

Obviously, one can increase total production by duplicating Yatai units.

4.2 Phase II. Mathematical Model for Divisional Seru Production System

When there are two or more workers involved in Seru production systems, we can benefit from classical assembly line balancing concepts. The following mathematical model has been used for assigning operations to stations (2 or 3) and minimizing the Cycle Time (and hence maximizing the output rate) without violating precedence relations. Objective function as given in Equation (3) minimizes the cycle time. Equation (4) guarantees that each task is assigned to a station. Equation (5) makes sure that station time at each station does not exceed the cycle time. Equation (6) maintains precedence relations where *task b* is an immediate successor of *task a*. In other words, *Task b* can only be performed after *task a* is performed either in the same station or in one of the later stations. This is repeated for all arcs *(a,b)* in the assembly network.

Indices:
i operation index
j workstation index

Parameters:
t_i *assembly time for operation i*
n *number of tasks*
m *number of workstations, number of workers*

Decision variables:
CT *Cycle Time*
x_{ij} *1 if task i is assigned to workstation j, 0 otherwise*

Objective Function:

$$\text{Minimize } z = CT \quad (3)$$

Subject to:

$$\sum_{j=1}^{m} X_{ij} = 1 \qquad i = 1, 2, \ldots, n \quad (4)$$

$\sum_{i=1}^{n} t_i \; X_{ij} \leq CT \qquad j = 1, 2, \dots, m \qquad (5)$

$X_{br} \leq \sum_{j=1}^{r} X_{aj} \qquad r = 1, 2, \dots, m$ and for all (b,a) (6)

In this case too, production rates can be calculated by using the Cycle Times determined after mathematical model is solved.

4.3 Phase III. Multi-Product Multi-Period Assembly System Design

In this section, a mathematical model for multi-product and multi-period assembly system design has been developed. We find out the operator distribution over four different periods for four different products so that the demand of each product is met and the available number of workers are not exceeded. The results for different value of ‘f’ (percentage of demand that must be produced at each period) are also shown along.

Indices:

r product index
t period index
k index for number of workers

Parameters:

PR_{rk} *production rate of product r with k workers*
a number of products
b number of worker levels
c number of periods
d_r *demand for product r*
f percentage of demand that must be produced in each period

Decision variables:

X_{rtk} *1 if product r is chosen for period t with k number of workers, 0 otherwise*
m_t *number of workers required for period t*
M Number of workers needed during the study period

Objective function:

Minimize z = M (7)

Subject to:

$\sum_{r=1}^{a} \sum_{k=1}^{b} k \times X_{rtk} = m_t \qquad for\ t = 1,2, \dots, c \qquad (8)$

$m_t \leq M \qquad for\ t = 1,2, \dots, c \qquad (9)$

$\sum_{k=1}^{b} PR_{rk} \times X_{rtk} \geqslant f \times d_r \qquad for\ r = 1, 2, \dots, a;\ t = 1,2, \dots, c \qquad (10)$

$\sum_{t=1}^{c} \sum_{k=1}^{b} PR_{rk} \times X_{rtk} \geqslant d_r \qquad for\ r = 1, 2 \dots, a \qquad (11)$

Here, equation (7) is the objective function which minimizes the manpower level. Equation (8) calculates the required number of workers for each period. Equation (9) is to make sure that at each period the total number of required workers does not exceed the total number of workers. Equation (10) makes sure that at least *f%* of each product is produced at each period. Equation (11) confirms that demand is met or exceeded for each product.

5. Results and Discussion

In this section, four different products (A, B, C and D) have been considered for four-week period. Precedence relations for products along with processing times are given in Appendix. Three different combinations of workers namely, one-worker arrangement, two-worker arrangement and three-worker arrangement have been considered for each product.

5.1 Results for Phases I and II

The detailed results for Phases I and II are shown in Table 1. This includes task assignment to stations and corresponding cycle times. The summary of results is presented in Table 2. In a week normal working time for a single shift schedule is 40 hours. So, there are 40×60 minutes = 2400 minutes. As a result, weekly production rate for product A when 1 worker is used (in other words, 1 Seru unit) is = $\frac{2400}{42} = 57.14$.

Table 1. Task Assignment to Stations and Cycle Time for Phases I and II

Product	# workers	Task and Times	Station1	Station2	Station3	Cycle Time
A	1	Tasks	1,2,3,4,5,6	-	-	
		Times	*10,8,5,7,3,9*	-	-	
		Station Time	42			42
	2	Tasks	1,2,3	4,5,6	-	
		Times	*10,8,5*	*7,3,9*	-	
		Station Time				23
	3	Tasks	1,3	2,4	5,6	
		Times	*10,5*	*8,7*	*9,3*	
		Station Time				15
B	1	Tasks	1,2,3,4,5	-	-	
		Times	*7,5,8,10,6*	-	-	
		Station Time				36
	2	Tasks	1,2,3	4,5		
		Times	*7,5,8*	*10,6*		
		Station Time				20
	3	Tasks	1,3	2,4	5	
		Times	*7,8*	*10,5*	*6*	
		Station Time				15
C	1	Tasks	1,2,3,4,5	-	-	
		Times	*6,4,3,7,8*	-	-	*28*
		Station Time				
	2	Tasks	1,2,3	4,5		
		Times	6,4,3	*7,8*		*15*
		Station Time				
	3	Tasks	1,2	3,4	5	
		Times	*6,4*	*3,7*	*8*	*10*
		Station Time				
D	1	Tasks	1,2,3,4	-	-	
		Times	*5,6,8,7*	-	-	*28*
		Station Time				
	2	Tasks	1,2	3,4		
		Times	5,6	*7,8*		*15*
		Station Time				
	3	Tasks	1,2	3	4	
		Times	*5,6*	*8*	*7*	*11*
		Station Time				

Table 2. Summary for cycle time/weekly production rate

Product	CT/production rate for 1 worker	CT/production rate for 2 workers	CT/production rate for 3 workers
A	42min / 57.14 units	23 / 104.34	15 / 160
B	36 / 66.66	20 / 120	15 / 160
C	28 / 85.71	15 / 160	10 / 240
D	26 / 92.30	15 / 160	11 / 218.18

5.2 Results for Phase III

Three different demand data sets with different values of f (percentage of demand that must be produced at each period) is experimented with to check the impact on assignment and number of workers for varying demand. At first f= 20% was applied and later f= 0%, 5%, 10%, 15% and 25% was also checked. This approach is followed to observe the impact of forced production on workers requirement and worker assignment for different products on different period. Demand values are obtained randomly from uniform distribution. For example, demand value in data set 1 for product A, B, C and D are 500, 600, 800 and 820, respectively. Three different worker combinations are considered namely 1 worker, 2 workers and 3 workers. 1 worker option means 1 seru unit, 2 workers option means a divisional seru that consists of two workers and 3 workers option means a divisional seru with 3 workers. work in the same line. In the notation (m×n) the first digit indicates which option and second digit indicates how many of those option are required. The results for different data sets are presented in Tables 3, 4, and 5.

Table 3. Manpower distribution for multi-period (demand data set 1)

	Period 1	Period 2	Period 3	Period 4	Demand of Products
Product A	(1×2) = 2	(1×1), (2×1) = 3	(1×2) = 2	(1×2) = 2	500
Product B	(1×2) = 2	(1×3) = 3	(1×2) = 2	(1×3) = 3	600
Product C	(1×2) = 2	(1×2) = 2	(1×4) = 4	(1×2) = 2	800
Product D	(1×3) = 3	(1×2) = 2	(1×2) = 2	(1×1), (2×1) = 3	820
Total Manpower, mj (Each period)	9	10	10	10	

Table 4. Manpower distribution for multi-period (demand data set 2)

	Period 1	Period 2	Period 3	Period 4	Demand of Products
Product A	(1×2) = 2	(1×2) = 2	(1×2) = 2	(1×2) = 2	300
Product B	(1×1) = 1	(1×1) = 1	(1×1) = 1	(1×1) = 1	200
Product C	(1×1), (2×1) = 3	(1×3) = 3	(1×3) = 3	(2×2) = 3	1000
Product D	(2×1) = 2	(2×1) = 2	(2×1) = 2	(1×2) = 2	500
Total Manpower m_j (Each period)	8	8	8	8	

Table 5. Manpower distribution for multi-period (demand data set 3)

	Period 1	Period 2	Period 3	Period 4	Demand of Products
Product A	(1×4), (3×1) = 7	(1×6) = 6	(1×6), (2×1) = 8	(1×4), (2×1) = 6	1500
Product B	(1×4) = 4	(1×5) = 5	(1×4) = 4	(1×4), (2×1) = 6	1200
Product C	(1×4) = 4	(1×2), (2×1) = 4	(1×4) = 4	(1×4) = 4	1400
Product D	(1×2), (2×1) = 4	(1×4) = 4	(1×1), (2×1) = 3	(1×1), (2×1) = 3	1000
Total Manpower (Each period) m_j	19	19	19	19	

From Table 3 it is it is found that product A needs 2 yatai units in period 1, in period 2 it needs 1 yatai unit and 1 divisional unit with 2 workers and in both periods 3 and 4 it needs 2 yatai units. In Table 4 and Table 5, different demand data is used to see how worker assignment is affected for different products in a dynamic demand environment. The results show that we can successfully reduce the number of workers by varying the number of workers assigned to products in different periods.

Table 6, Table 7 and Table 8 show the number of workers required at each period when different ‘f’ values are used for different demand values. From these results it is found that when units equivalent to 25% of total demand (equal product at each period since there are 4 periods) is forced to produce at each period number of required worker increases for all demand data set.

Table 6. Summary table for different f values of data set 1

	Demand of Product A	Demand of Product B	Demand of Product C	Demand of Product D
	500	600	800	820
	Number of workers required at Period 1	Number of workers required at Period 2	Number of workers required at Period 3	Number of workers required at Period 4
f = 0%	10	10	9	10
f = 5%	10	10	10	10
f = 10%	10	10	9	10
f = 15%	10	10	10	10
f = 20%	9	10	10	10
f = 25%	12	12	12	12

Table 7. Summary table for different f values of data set 2

	Demand of Product A	Demand of Product B	Demand of Product C	Demand of Product D
	300	200	1000	500
	Number of workers required at Period 1	Number of workers required at Period 2	Number of workers required at Period 3	Number of workers required at Period 4
f = 0%	7	7	7	7
f = 5%	7	7	7	7
f = 10%	7	7	7	7
f = 15%	7	7	7	7
f = 20%	8	8	8	8
f = 25%	8	8	8	8

Table 8. Summary table for different f values of data set 3

	Demand of Product A	Demand of Product B	Demand of Product C	Demand of Product D
	1500	1200	1400	1000
	Number of workers required at Period 1	Number of workers required at Period 2	Number of workers required at Period 3	Number of worker srequired at Period 4
f = 0%	19	19	19	19
f = 5%	19	19	18	19
f = 10%	19	19	19	19
f = 15%	19	19	18	19
f = 20%	19	19	19	19
f = 25%	20	20	20	20

6. Conclusion

Based on the results shown in Tables 3, 4 and 5, we can conclude that the mathematical model proposed in Phase III can find minimum number of workers in a multi-period environment by varying workers to be assigned to different products. This helps to reduce the overtime or temporary worker arrangements and thus brings stability to the organization. It is important to note that the model did not always pick the yatai as the solution even though yatai has higher efficiency than 2-worker and 3-worker divisional seru systems. The main reason for that is the model picked among solutions that meet the demand without increasing the total number of workers. As one can see in Tables 6, 7, and 8, as we force the model to produce evenly every period, then the number of workers needed increases. This implies that system efficiency drops and labor costs are adversely affected. Labor skills and training issues can be added to this work as a future expansion.

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Biographies.

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Md Abdullah has completed his MS in Industrial and Systems Engineering at Ohio University. He has experience in implementing 5S, Six Sigma, Lean, Warehouse distribution and supply chain management. He carried out projects on Scheduling, Genetic Algorithm, Simulation and Java. His interest areas are manufacturing system design, assembly line balancing, seru production systems and software development.

Appendix. Precedence Networks for products.

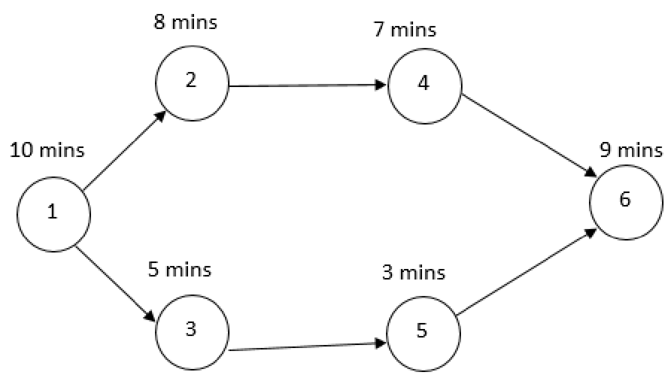

Figure 1. Precedence relation for product A

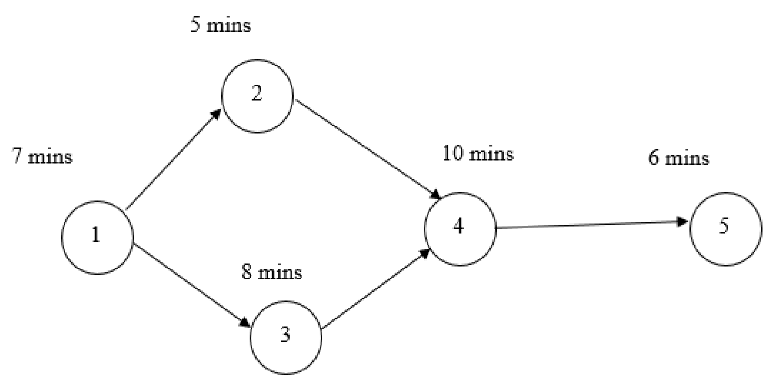

Figure 2. Precedence relation for product B

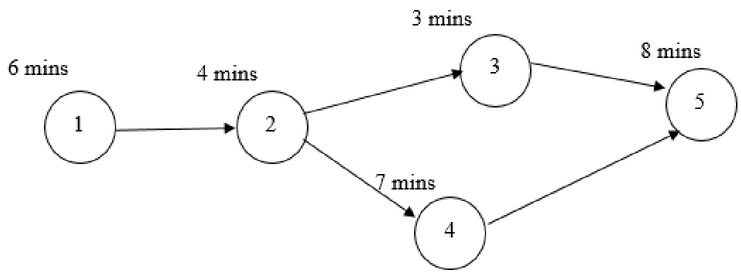

Figure 3. Precedence relation for product C

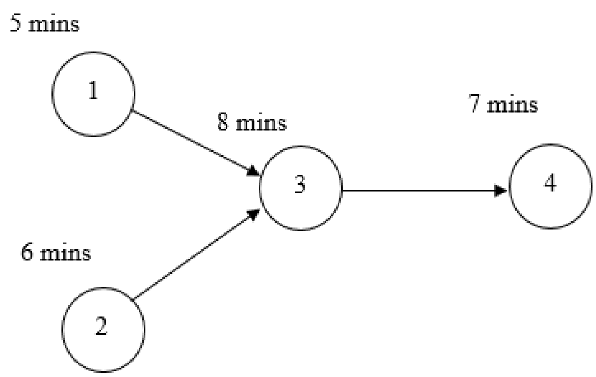

Figure 4. Precedence Relation of Product D