Poon's Formation of Seru-Flow Production on Manufacturing Medium Quantity

William W.T. Poon[1,2,3]* and Philip K.I. Chan[1,2,3,4]

[1] **Stanford University, Stanford, California, USA 94305**
[2] **University of California, Berkeley, Berkeley, CA, USA 94720-1234**
[3] **California Status University ,Monterey Bay, 100 Campus Center, Seaside, CA, USA 93955-8001**
[4] **Stanford, Berkeley, Monterey Postdoc Advisor**

*** research@williampoon.com, (852) 3465 9882**

Keywords: seru flow production; cellular production; assemble line balance; cell formation; learning curve model

Manufacturing medium to medium-large quantity in seru (cellular) production has been a large question for many years, lot of researches on using different methods or different formations of seru production to improve the line capacity, efficiency, equipment usage and implementation on automated machine. In this paper, an innovated formation of seru production, Poon's formation of seru-flow production, is presented. This formation is a combination of seru production and flow production, long conveyor is reinstated while divisional seru is applied. Therefore, the Poon's formation of seru-flow production inherited the benefit from both seru production and flow production. It is capable to improve the learning curve, line capacity, equipment usage and implementation on automated machine against seru production, while also capable to retrieve most of the imbalance loss against flow production.

On the other hands, a numerical model, Poon's model of labour learning curve, based on Wright's model is presented. The aim of this numerical model is to predict the increment in production rate of different length of task over the total produced quantity. Thus, the performance of the Poon's formation of seru-flow production is compared and is justified by the Poon's model of labour learning curve, with comparison of actual figures from an operating high quality toy manufacturing factory.

1 INTRODUCTION

In manufacturing industry, traditionally there are three main method of production, job production, batch production and mass production, while different method suitable for different type of product in different manufacturing lot. [1] Furthermore, new methods of production is continuously developing according to technology change, market change and geographical location. Flow production, Cart pulling method, relay method, Boutique manufacturing, seru (cellular) production has been developed to fulfil different production criteria. Among all different production methods, flow production has been widely used in 20th century and shown remarkable advantage on mass production; while seru production has been a hot topic for last two decades and shown advantage on small manufacturing lot. [3]

Seru production is widely used in Japan and reported very successful on improving production performance against flow production. It is on the background of Japan's major manufacturing order has been moved outside for last two decades, manufacturing order become smaller and more variation (non-standardise). [3] The key concept of seru production (usually) has no conveyor and usually has U-shape station/production line. There are three main type of seru production system, they are divisional seru, rotating seru, Yatai. [4] Seru production is highly flexible especially able to start or change production efficiently compared with flow production, most importantly the imbalance occurs in flow production is eliminated. However, seru production shows limitation on line capacity, efficiency, equipment usage and implementation on automated machine.

In many manufacturing scenario, especially nowadays China, manufacturing lots is not large enough to perform prefect flow production to eliminate the imbalance, however much higher than the volume that traditional seru production could be produced efficiently. These medium sizes of manufacturing quantity are classified as medium quantity in this paper. Medium quantity is very common in different industries, the production method to improve the performance on producing this quantity is very important.

On the other hands, one of the limitations on traditional seru production is automation implementation. In modern manufacturing, lot of machineries are beginning used not only in large quantity, but also in medium quantity. For medium quantity semi-automation is widely applied, especially in the assemble line. Most of those machines are non-stop and is operating in high production rate, therefore production method able to match the pace of those machine is a must.

In this paper, Poon’s method of seru-flow production will be presented to counter the above problem. Poon’s method of seru-flow production method is a mixture of seru production and flow production, and is suitable for producing medium quantity. This method has low imbalance lost and has good learning curve effect. Furthermore, automation can be implemented on Poon’s method of seru-flow production.

Poon’s model of labour learning curve will be presented to model the performance of Poon’s method of seru-flow production. This model is capable to predict the man hour required to produce certain amount of product with accounting the learning curve effect for operation at different task length. The performance of Poon’s method of seru-flow production will be compared with the performance of seru production, flow production and balanced flow production. Furthermore, the result predicted by this model will be compared with actual figures from industry. Finally, the result presented will be analysed and discussed.

2 POON’S FORMATION OF CELLULUR-FLOW PRODUCTION

Production method to produce medium quantity is important to different industries nowadays especially in China. Interestingly, both seru production and flow production has its own advantage and are showing similar performance on medium quantity. In order to understand the reason, performance and reason is reviewed from small quantity to large quantity. In small quantity, seru production has a dominated advantage on no imbalance lost. When quantity increase, production rate of flow production improve, gradually to a certain point that improvement equalised the imbalance lost. Eventually, that improvement takes a dominated effect in large quantity. At that quantity, flow production has advantage over seru production. This phenomenon, improvement in production rate after finishing certain number of product, has been defined as learning curve effect. That is to say, learning curve for the same product is different between seru production and flow production. The primary different between those two production method is the task length. Kilbridge M. suggested that labour learning curve is affect by the task length, the shorter the task length, the quicker the learning time, the faster the production rate improves.[6] On the other hands, it is well know that, the longer the task length, the less imbalance lost occurs. Therefore, by selecting an optimal task length to minimise the imbalance lost and to maximise the learn curve effect could improve the production performance on medium quantity.

In order to improve the production performance on medium quantity, an innovated production method, Poon’s formation of seru-flow production, is developed based on seru production but in concept of flow production. The objective of this method is to optimise the overall task length to retrieve most of the imbalance lost while maintaining a good learning curve. Furthermore, the overall pace must match the pace of automations.

In Poon's formation of seru-flow production method, there are two layers of balancing are performed. On the first layer of balancing, various operations are merged into various operation groups in perspective of flow production, i.e. grouping; In perspective of seru production, production process is divided into various operation group consists of several operations similar to divisional seru. The standard operation time between operation groups must be similar or similar to its multiple, also must be in the range of optimal task length. One operator is assigned into each operation group, therefore, it becomes a seru or short seru with task length short enough to maintain a good learning curve. From another point of view, each short seru (operation group) can be treated as an operation in flow production. Thus, on the second layer of balancing, production line is balanced as the same method on flow production by treating each short seru (operation group) as an operation. On this balancing, short serus (operation groups) are multiplied not only to match the production rate required, but also to match the production rate of machineries or automations. Inherited from flow production short serus (operation groups) are parked beside of a long conveyor. Therefore, operators performing flow production while working in seru production mode. From seru production perspective, Poon's formation of seru-flow production, is a multiplied version of divisional seru but with a long conveyor which seru production aim to eliminate. From flow production perspective, Poon's formation of seru-flow production, is a flow production merging to short serus (operation groups) instead of division of labour which most of the flow production method empathize.

In figure 1, a schematic of Poon's formation of seru-flow production is illustrated, where 1 to 8 are operation tasks. Figure 1, shows a conveyor belt parked with short seru booths and machineries with automation fitted in. Similar to flow production, short seru booths are working at the similar pace as automations. Multiple operations are merged and perform in various short seru booth. This formation certainly inherited the nature of seru production, however, the key difference from other variation of seru production is the use of conveyor, which is also opposed the key concept of seru production. Therefore, this innovative method strictly speaking cannot be classified as a variation seru production, thus, is named Poon's formation of seru-flow production.

3 MATHEMATICAL COMPAREISON

3.1 SIMPLE SCENARIO

In order to illustrate the Poon's formation of seru-flow production mathematically, a simple scenario with 9 operations is setup and length of each operation is shown in table 1. In table 1, worker used of different methods are shown and their production rate is calculated. Those methods are seru production, where one worker performs all 9 operations; balanced flow production, where 35 workers are used and has no imbalance; flow production, where 11 workers are used and imbalance is occurred; Poon's formation of seru-flow production, where 9 workers are used and have small imbalance lost. Data shown in table 1 are theoretical calculation, factors on site are ignored. It can be seen from table 1, seru production and balanced flow production is theoretically most efficient and has no imbalance lost, while balanced flow production has a high production rate with high labour usage. Table 1 also shows that flow production have a high imbalance lot, while Poon's formation of seru-line production have a small imbalance lost.

3.2 POON'S MODEL OF LABOUR LEARNING CURVE

As mention in section 2, apart from imbalance lost, the labour learning curve also a key factor to affect the production rate over time. Therefore, it is important to create a model to model the production rate against the task length over time. Furthermore, the model should be able to reflect the effect on the imbalance lost and the labour learning curve. Poon's model of labour learning curve is built to model the production rate of operations with different task length against produced quantity. Moreover, this model also taking the effect of both imbalance lost and labour learning curve into account. Furthermore, factors other than imbalance and labour learning curve are ignored i.e. material shortage.

In order to model the labour learning curve, Wright's learning curve model is used:

$$l_x = \alpha x^{log_2 \beta} \quad \text{--------------- (1)}$$

where $\mathbf{l_x}$ is time required to perform an operation after $\mathbf{x}^{th}$ operations has been performed; α is the time needed to perform the first operation; β is the learning rate in percentage.

The Wright's learning curve model account lot of factors, automation, improvement of machinery, improvement in technology other than labour learning when production quantity increase infinitely. Therefore, the improvement of performance due to labour learning only has celling effect unless other factor improves. In real operation, time required to perform an operation will not continuously decrease to zero or tend to zero after huge amount of operations been performed, therefore, improvement achieved only by labour learning have a limited factor. Thus, equation 1 can be rewritten as:

$$l_x = \alpha(x^{log_2 \beta} + \gamma) \quad \text{--------------- (2)}$$

where γ is the constant represent factors other than worker's experience

In industrial practise, time needed to perform the first operation is meaningless for a significant order, i.e. quantity more than 500. A meaningful task length will be represent the time needed to perform operation after a significant amount of operations are performed. Usually, in mass production toys industry, task length is estimated around quantity of 3000. Therefore, a corrective factor can be put in to represent that, mathematically can be written as:

$$\alpha = \mathrm{a} l_t \quad \text{--------------- (3)}$$

where **a** is a constant; $\mathbf{l_t}$ is the task length

As mention in section 2, learning curve for different task length is different. The longer the task length, the harder to learn, the lower the learning rate, therefore, β increase when task length increase. However, learning rate depends on a lot of different factors, when the task length is very small or tend to zero, learning rate will not tend to zero and stay in a high percentage, therefore, β has a base factor independent to the task length. By observation, the relationship between learning rate and task length is non-linear, most of the time, double or halve the task length only affect small percentage of learning rate, and the rate of change in learning rate is similar when every double or halve of task length, therefore, β may be proportional to logarithm of task length. By assuming β proportional to base 2 logarithm of task length with an independent base factor, mathematically can be written as:

$$\beta = \mathrm{b} + \frac{log_2(l_t)}{100} \quad \text{--------------- (4)}$$

where **b** is a constant to represent the minimum learning curve

By substituting equation 3 and equation 4 into equation 2, equation for the time required to perform an operation with certain task length can be found. Poon's model of labour learning curve can be written as:

$$l_x = al_t x^{log_2[b+log_2(\frac{l_t}{100})]} + cl_t \quad \text{---------------} \ (5)$$

where is **a, b,** c are parameters of the model to model different scenario

by using equation 5, total man hour is needed to produce certain units can be predicted by summing up the time required to perform each operation numerically. Therefore, man hour required against production quantity with different task length can be predicted.

3.3 RESULT FROM NUMERICAL MODEL

Apart from imbalance lost, the main different between production methods shown on table 1 are task length performed by workers. Operation with the worst learning rate is on the longest task on each method. Therefore, the longest task length is taken to model the learning curve of each production method shown on table 1. In order to model the man hour required more realistically an initial setup time **d** (in hour) for each worker used is added, for example, on 35 workers used production method, when **d** = 0.5, 17.5 hours initial setup time is added. By using the parameter shown on table 2 to perform the Poon's model of learning curve, man hour required against production quantity for each production method listed on table 1 are calculation. After that, the result is multiply by the imbalance lost and quantity of workers used, result are shown in figure 2 and figure 3.

In figure 2, man hour required against production quantity for different methods, seru production, flow production, balanced flow production and Poon's method of seru-flow production for production quantity from 0 to 5,000 are shown. It can be seen that, in small production quantity (under 3,000), seru production is most efficient, balanced flow production is most in efficient due to the setup time. At production quantity around 3,500, Poon's method of seru-flow production begin to be more efficient than seru production, while flow production and balanced flow production showing less efficient. At production quantity around 5,000, balanced flow production begin to have equal efficiency with flow production.

In figure 3, man hour required against production quantity for different methods for production quantity from 0 to 30,000 are shown. It can be seen that, in production quantity over 15,000, Poon's method of seru-flow production and balanced flow production are more efficient than other methods and their performance are similar.

4 ACTUAL FIGURES FROM INDUSTRY

A product from Dream Creation Limited, which similar to the simple scenario shown on table 1, is selected to be investigated in order to justify the result from Poon's model of learning curve. Dream Creation Limited is an operating OEM factory to produce high quality toys from Bandai. The company is located in China and have average 700 workers with over 300 experienced workers on assemble department. Dream Creation Limited is a subsidiary of Perfectech Group which is listed in Hong Kong Stock exchange (Stock code 765). Dream Creation has production line on both flow production and seru production on assemble department, automation and semi-automation equipment has been implemented in the production line. Furthermore, Dream Creation Limited has implemented a specially designed bonus system to ensure the motivation of workers in all manufacturing departments. Dream Creation Limited is controlled by Dr. Poon wai tsun William, continuously carries the research and experiment on manufacturing improvement.

The investigation result and experimental result of the above product is shown on table 3 and table 4 respectively. In table 3, the investigation result from line leaders are shown. According to line leader for seru production, production rate are vary a lot between workers, this variation is happen in both new workers and expert workers, especially new workers. For flow production, according to the line leader, production rate becomes very stable after a period of running, normally after 3 days (33 hours). It must be note that, on flow production some semi-automation is installed, therefore the production rate should be higher than theoretical production rate. In table 4, experimental result of hourly production rate for flow production and Poon's formation of seru-flow production is shown. The experiment is done by new workers for 8 hours.
To compare the Poon's model of learning curve with the investigation result on table 3, the modelling result is plotted in production rate against production quantity and is shown in figure 4, It can be seen in figure 4, production rate of seru production is around 30 on very small quantities and is over 50 on large quantities. The modelling result on seru production is very similar to the investigated result shown on table 3. For flow production, production rate is over 50 on large quantities, it is lower than the investigated result shown on table 3, it is likely because of the semi-automation on the flow production line.

To compare the Poon's model of learning curve with the experimental result on table 4, production rate against production hour after production start is plotted in figure 5, In figure 5, production rate of seru production and flow production both experimentally and modelled by Poon's model of learning curve are indicated. It can be seen in figure 5, production rate of flow production increase from around 20 to around 40 for both experimental and modelled result. Furthermore, production rate of Poon's formation of seru-flow production increase from around 22 to around 44 for both experimental and modelled result. Although the experimental result and modelling result is not match exactly, as many factory yield the actual production performance, the model able to closely predict the production performance of different production methods.

5 DISCUESSION

By using the Poon's model of labour learning curve, the production performance of different production method seru production, flow production, balanced flow production and Poon's method of seru-flow production can be predicted without the influence of other factors i.e. automation, material storage, worker difference. In figure 3, the performance of balanced flow production and Poon's method of seru-flow production is very close, while the performance of seru production and flow production also very close. In order to study the performance between those 4 methods clearly, performance of each method other than seru production is normalised by the performance of the seru production and is shown in figure 6.

In figure 6, man hour required for flow production, balanced flow production and Poon's method of seru-flow production are normalise by the man hour required for the seru production and is plotted against production quantity. It can been seen that, in small quantity, all other methods are not as efficient as seru production. It is partly because the initial setup time, and party because the imbalance lost while the learning curve effect is insignificant.

At production quantity from 3,500 to 22,000, Poon's method of seru-flow production is most efficient. About 5% less man hour required against seru production, and about 8% less man hour required against flow production. It is at the point where learning curve effect is significant enough to equalise the 3% imbalance lost. At these quantities, because production of the balanced flow production is split among 4 workers, the improvement by learning curve in production rate at the same quantity is smaller. Thus, Poon's method of seru-flow production is more efficient than seru production and balanced flow production in these quantities. This is also classified as medium quantity in this paper.

At quantity over 22,000, balanced flow production is most efficient. It shown about 7% less man hour required against seru production. It is at the point where learning curve effect is significant and marginal increase by learning curve effect is small, the production rate is more or less stable. Same as the result indicated, it is well know that balanced flow production has no imbalance and has good learning curve, and is good for large quantity. However, it is also well known that performing balanced flow production in real life has a lot of constrain.

For flow production, which is widely use in industries, has similar performance with seru production in large quantity. The reason for flow production widely use in industries is because the production lead time. Seru production only have a low production rate, therefore, flow production has to be used even when seru production is more efficient. However, when Poon's method of seru-flow production compare to flow production, Poon's method of seru-flow production not only able to perform similar production rate, but also save about 8% of man hour required. Therefore, Poon's method of seru-flow production is a good replacement of flow production in industrial production.

5 CONCLUSION

In this paper, Poon's model of labour learning curve has been presented, and is shown matching with experimental result and investigated result. This model able to predict the production time required after a certain amount of product been produced, while taking the learning curve effect into account. This model is also capable to predict the man hour required to produce certain amount of product with accounting the learning curve effect for operation at different task length. Furthermore, modelling parameter to predict the production of toys industry has been presented. Moreover, the use of Poon's model of labour learning curve is demonstrated and the performance of different production method is modelled.

In this paper, Poon's method of seru-flow production has been presented. This method is a mixture of seru production and flow production, has low imbalance lost and has good learning curve effect. Conveyor belt is used in this method and the production rate similar to flow production. Performance of Poon's method of seru-flow production has been predicted by Poon's model of labour learning curve. Performance of Poon's method of seru-flow production has been compared with different production method seru production, flow production, balance flow production. It has been shown that Poon's method of seru-flow production able to improve the performance of production on medium quantity. When comparing with flow production, Poon's method of seru-flow production able to reduce 8% of man hour on medium quantity. When comparing with seru production, Poon's method of seru-flow production able to reduce 5% of man hour on medium quantity. Poon's method of seru-flow production is therefore can be concluded a good replacement of seru production and flow production on medium quantity.

In future, more experimental result is needed to justify the Poon's model of labour learning curve. More experimental result is needed to compare Poon's method of seru-flow production with seru production and flow production. Furthermore, more implementation study on Poon's method of seru-flow production is needed to be done, especially with different industry.

Op. ID	Op. Len.(s)	Seru		Bal. Flow		Flow		Poon's Cell-line	
		Worker	Time	Worker	Time	Worker	Time	Worker	Time
1	8	1	70	4	2	1	8	2	8
2	8			4	2	1	8	2	8
3	6			3	2	1	8	1	8
4	10			5	2	2	8	2	8
5	6			3	2	1	8	2	8
6	8			4	2	1	8		
7	8			4	2	1	8		
8	10			5	2	2	8		
9	6			3	2	1	8		
Workers			1		35		11		9
Item per min			0.86		30		7.5		7.50
Item / min / worker			0.86		0.86		0.7		0.83
Imbalance lost			0%		0%		20.5%		2.8%
Item per hour			51		1800		450		450

Table 1, simple scenario with 9 operations with calculation of theoretical performance of 4 types of production method, seru production, balanced flow production, flow production, Poon's formation of seru-line production.

a	2.2
b	0.85
c	0.5
d	0.5

Table 2, Modelling parameter of Poon's model of labour learning curve.

	Prod. Rate per hour
Seru (new)	30-35
Seru (expert)	50-60
Flow (expert)	60

Table 3, Investigation result from line leaders: Seru Production hourly rate for new workers and expert worker after long run; Flow Production hourly rate for expert worker after long run.

Hour	Flow	Poon's
1	23	22
2	31	26
3	39	30
4	40	32
5	40	36
6	40	42
7	40	44
8	40	43

Table 4, Experimental result of hourly production rate for flow production and Poon's formation of seru-flow production on new workers for 8 hours.

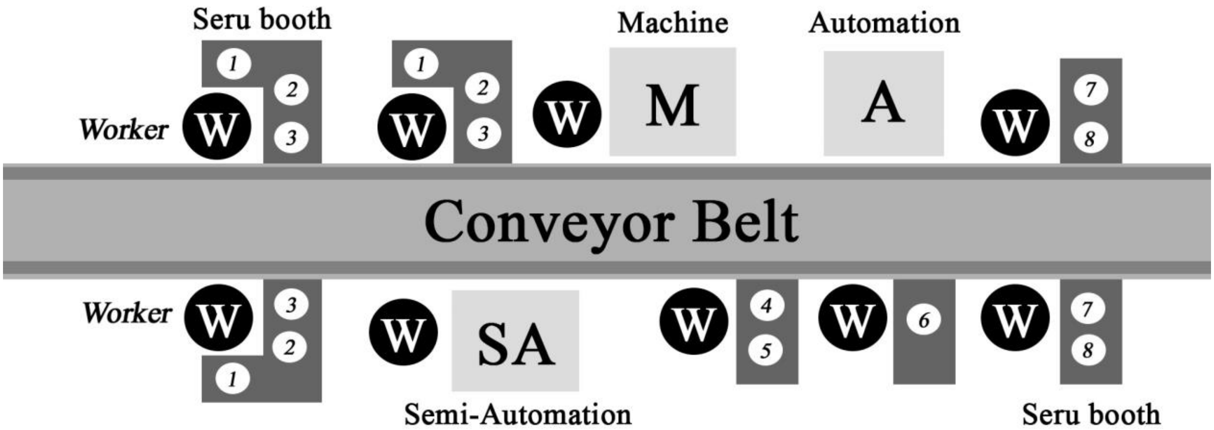

Figure 1, Schematic of Poon's formation of seru-flow production. Task, seru booth, machine, automation, semi-automation and conveyor belt are indicated.

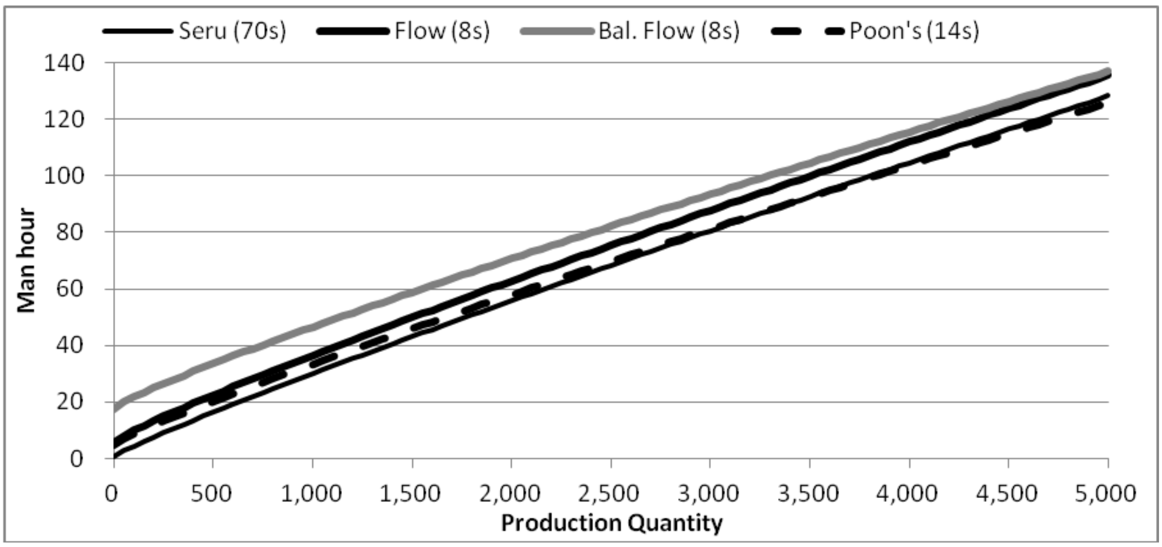

Figure 2, Man hour predicted by Poon’s model of labour learning curve against production quantity on production quantity from 0 to 5,000. Production performance of seru production, flow production, balanced flow production and Poon’s formation of seru-flow production are indicated.

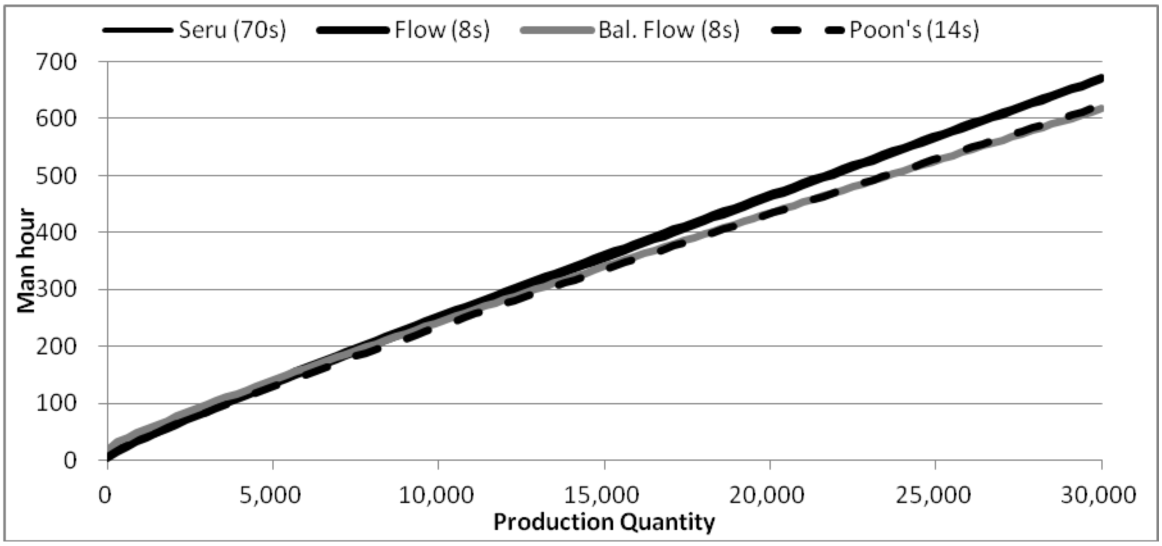

Figure 3, Man hour predicted by Poon’s model of labour learning curve against production quantity on production quantity from 0 to 30,000. Production performance of seru production, flow production, balanced flow production and Poon’s formation of seru-flow production are indicated.

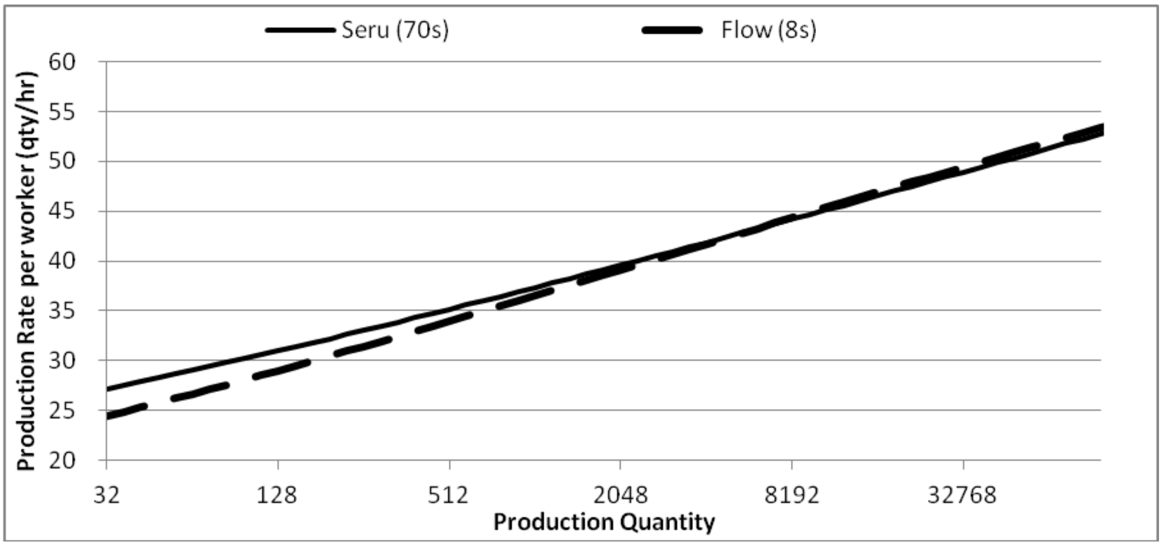

Figure 4, Production rate against production quantity in base 2 logarithm scales indicate the production rate of seru production and flow production.

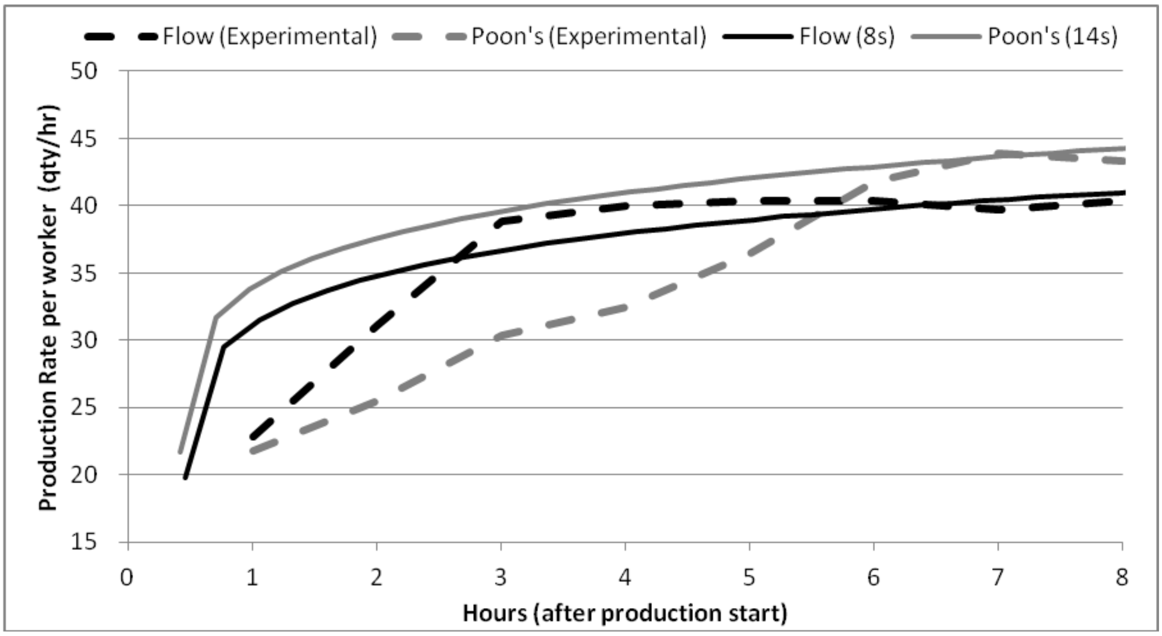

Figure 5, Production rate against production hour after production start. Production rate of seru production, flow production experimentally and modelled by Poon's model of learning curve are indicated.

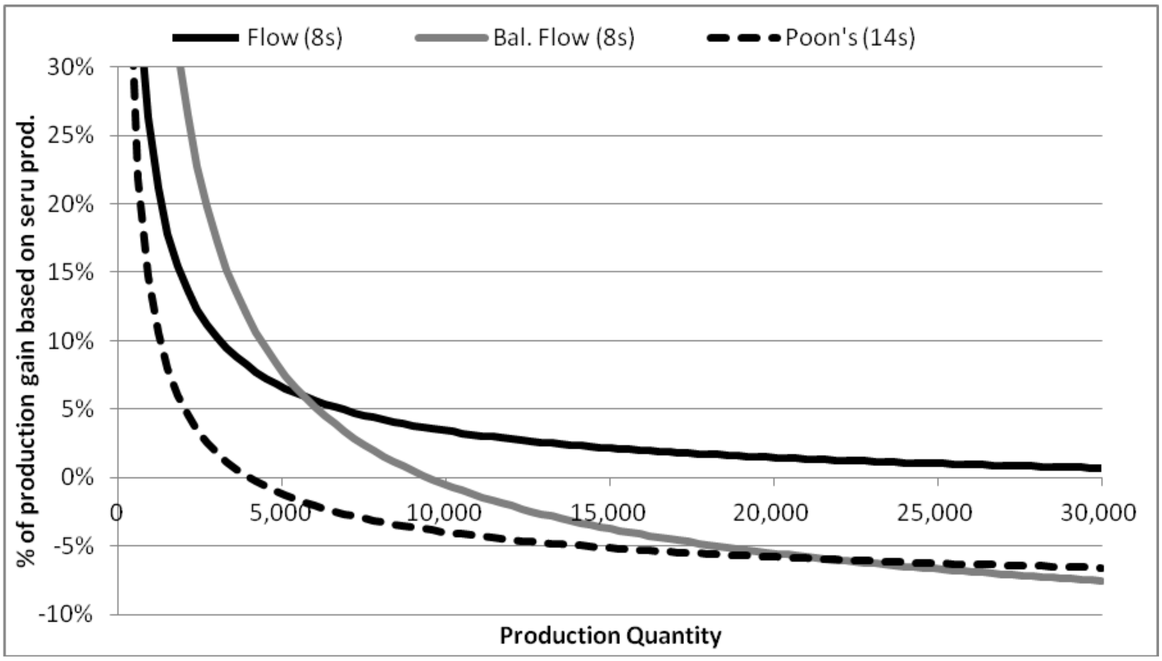

Figure 6, Production performance of flow production, balanced flow production and Poon's formation of seru-flow production normalised by seru production on production quantity from 0 to 30,000.

Acknowledgements

The authors sincerely thank Dr. Eric Tao of California State University Monterey Bay for his kind assistance and valuable advice in this study. The authors also express their heartfelt thanks to Bandai and Perfectech Group for their kind support and valuable advice in this study.

Reference

[1] **Wild R.** (1972) Mass-Production Management, John Wiley & Sons, Surrey, Great Britain

[2] **Chow W.M.** (1990) Assembly line design : methodology and applications, M. Dekker, New York

[3] **Liu C., Lian J., Yin Y., Li W.** (2010) Seru Seisan‐ an innovation of the production management Mode in Japan, Asian Journal of Technology Innovation, Vol.18(2), p.89-113

[4] **Liu C., Yang N., Li W., Lian J., Evans S., Yin Y** (2013) Training and assignment of multi-skilled workers for implementing seru production systems The International Journal of Advanced Manufacturing Technology, Vol.69(5), pp.937-959

[5] **Liu, C., Stecke K.E., Lian J., Yin Y.** (2014) An implementation framework for seru production, International Transactions in Operational Research, Vol.21(1), pp.1-19

[6] **Kilbridge, M.** (1961) A model for industrial learning cost, ABI/INFORM Collection, Vol.21(1), pp.516