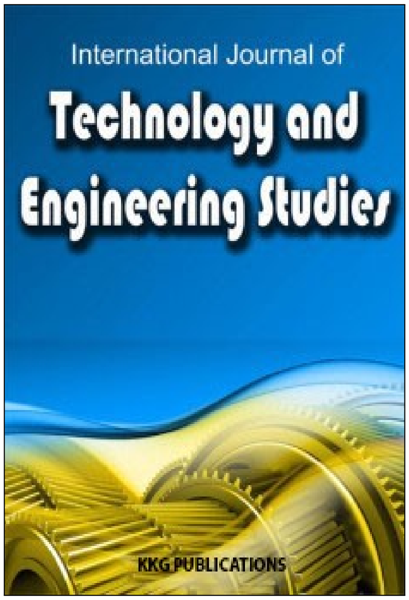

Key Knowledge Generation
Publication details, including instructions for author and subscription information:
http://kkgpublications.com/technology/

Manufacturing Line Balance and Impacts on Complexities

EDWARD KW LAW [1], WINCO KC YUNG [2]

[1, 2] The Hong Kong Polytechnic University,
Hong Kong, China

Published online: 17 August 2017

To cite this article: E. K. Law and W. K. Yung, "Manufacturing line balance and impacts on complexities," *International Journal of Technology and Engineering Studies,* vol. 3, no. 4, pp. 141-146, 2017.
DOI: https://dx.doi.org/10.20469/ijtes.3.40002-4

To link to this article: http://kkgpublications.com/wp-content/uploads/2017/3/IJTES-40002-4.pdf

KKG PUBLICATIONS

International Journal of Technology and Engineering Studies
vol. 3, no. 4, pp. 141-146, 2017

IJTES

MANUFACTURING LINE BALANCE AND IMPACTS ON COMPLEXITIES

EDWARD KW LAW [1]*, WINCO KC YUNG [2]

[1, 2] The Hong Kong Polytechnic University, Hong Kong, China

Keywords:
Multi-Model Work Flow
Mixed-Model Work Flow
Line Balancing
Information Entropy
Manufacturing Complexity
Structural Complexity

Received: 02 April 2017
Accepted: 09 June 2017
Published: 17 August 2017

Abstract. This article systematically organizes and reviews production line configuration that can affect manufacturing complexity. Empirical and exploratory studies were used for this review. Complexity impact on Smoothened Effect on individual product types is used to demonstrate as an added benchmarking in line balancing. Complexity issues have been discussed in the manufacturing field for some time but draw more attention recently. Manufacturers found it is important to ensure the assembly flow be manageable. Therefore, complexity should be considered as well in the optimization process. Structural and dynamic complexities are proposed to be considered a result of line balance and illustrated with a case study. Previous line balancing only focused on improving tangible benefits, such as reducing manpower or reducing the cycle time. This research provides a methodology to optimize line balancing while considering the complexities (normally regarded as intangible) during the optimization process.

INTRODUCTION

There are quite a number of Electronics Manufacturing Servicing (EMS) factories in many new industrial developing countries, for example China and South East Asia. Some of them are local companies, while many of the large companies are foreign-owned. Nearly all the electronics products consist of a Printed Circuit Board Assembly (PCBA) and a metal or plastic enclosure. Design is mostly done by the EMS customer. EMS manufacturer starts the process from Engineering by preparing the relevant work instructions, testing programs, and programming for Surface Mounted Technology (SMT) machine. Minor assemblies such as interconnects and mechanical systems can be outsourced to suppliers or sister companies.

Once the materials are ready, PCB assembly is started. There are many different processes that need to be prepared upfront to deal with a particular product. The preparation (set-up) of the production line for a particular product is quite time-consuming. Therefore, most of the EMS manufacturers would like to have a high volume production so as to justify the time consumed in the set up. Also, traditional production lines are relatively long and the process can be minimized for each work terminal.

Repetition of the same work trains the worker to be skilful for that particular portion of work, and hence the overall process is faster. Manufacturers have a fixed number of production lines. Therefore, the maximum number of products that can be produced at the same time is restricted accordingly. The same problem applies to the subassembly and final system assembly and test. In these developing countries, the product market is mostly overseas. Some customers with a strong brand name can give a high volume demand, and many manufacturing companies would like to get such orders. To win the business, the manufacturers would need to compete on the price of the manufacturing. Since there are already so many manufacturers in this market, the profits are very slim if not losing money. On the other hand, some customers with less strong brand names, or designing products for niche markets, can only have the less order quantity.

These customers are still very demanding on the quality and they would like to ensure their products will go through all the processes without missing any single production step. The long setup time and long production lines that most factories are equipped will make EMS not willing to manufacture these products. In most cases, only small factories can compete manufacturing products with small quantity. A good line balancing is, therefore, vital to the success of these companies.

However, it will become shifting to an extreme that the line configuration can be too complex for the production, planning, and management to deal with. Also, it will also complicate the execution if there are too many scenarios happening in the real situation. Therefore, it is necessary to measure the tangible effect of line balancing and the non-tangible effect of complexities.

*Corresponding author: Edward Kw Law
†Email: edward7kwlaw@gmail.com

LITERATURE REVIEW

Line Balancing Studies and Optimization Methods

Principle of Mixed Mode Line Balancing

[1] illustrated the basic principle of mixed mode line balancing with combined precedence diagram. He improved the line balancing with smoothened effect. [2] did a research to compare several heuristics based on the combined precedence diagram, and established a new mathematical model. The results show that the position of common tasks in the precedence diagram of the different models plays a significant role on both the CPU time and the unequal distribution of the total processing time of single models among work terminals. Moreover, solutions with respect to the number of required terminals will also affect CPU times. In some situation, we can decrease the CPU times considerably without deteriorating the system performance, by employing a reversed combined precedence diagram. [3] studied the behavior of dispatching for an Automatic Guided Vehicle System (AGVS) with an entropy-based approach. Similar to the rules for manufacturing as described above, there are also rules for the dispatching system such as Minimum Average of Empty Distance (MAED) and Minimum Sum of Empty Distance (MSED). Similar to balancing a production line in a factory, it is important to balance the loading of all the vehicles. He proposed a look-ahead AGV dispatching and used the Kullback-Leibler divergence principle to measure the contribution of dispatching toward the system laminar flow, based on the certain rules of setup. The approach is to measure the directed divergence between a probability distribution, P, and a reference distribution, Q.

The Kullback-Leibler information

$$KL(P,Q) = \sum_{i=1}^{n} p_i ln(\frac{p_i}{q_i}) \quad (1)$$

When the reference probability distribution is uniform, then

$$KL(P,Q) = -H(P) + ln(n) \quad (2)$$

The first term is the Shannon entropy and the second term is a constant. Therefore, if the factory is to balance the work, then the objective is to find a system configuration that gives the largest Shannon entropy. In principle, a similar approach can be used to find the optimal point for the manufacturing environment on the product mix ratio, number of machines, number of operations, etc. However, the combination in a manufacturing environment can be much more complex as there are more factors and combinations that affect the result. The interaction matrix should be able to help to visualize the combination systematically.

Optimization with Taguchi Method and Data Envelopment Analysis (DEA)

[4] devised a methodology to minimize the combination with an Orthogonal Array (OA). The methodology works well if we are only optimizing a single output. [5] derived a method with DEA to find the optimal input value to achieve the maximum performance across all the outputs. When we are considering several input factors and the output, the performance can be represented graphically as suggested by [6] and [7]. Although it is good to give a general idea of how the product mix will affect the performance of the waiting time, considering another criterion such as throughput will give another picture. A similar situation happens for the input factors. It is, therefore, necessary to find out the combined effect on the whole system performance. With the Taguchi and DEA method mentioned above, we should be able to find a good combination of different input factors on the overall system performance. [8] studied different solutions to line balancing, and summarized that finding just a single optimal solution to line balancing is NP-hard; finding all solutions with many terminals can take a considerable amount of time. Both DEA and Taguchi Method are trial and error methods by generating many combinations of line set up, and testing whether the solution is closer to the optimal. Therefore, it will also fall into the trap of NP-hard and consume lots of computation time before a certain amount of optimization is achieved. Furthermore, it will lose the insight on how the optimization is achieved as it is a trial and error (or experimental design) methodology. It is, therefore, needed to pursue further any latest methodology in the field that can achieve a more promising result.

Information Entropy

It has been more than 6 decades since information entropy was proposed by [9]. [10] reviewed the progress of its application to manufacturing complexity. There is a great progress in the last two decades in the application of information entropy of manufacturing systems. It affects not just manufacturing systems, but also the entropy models or function can be applied to analyze the relationships among facilities, products, and tasks in the systems qualitatively and quantitatively. [10] also commented the dilemma in planning a manufacturing system. On one hand, manufacturing systems with a smaller entropic value may lack the flexibility; on the other hand, manufacturing systems with a higher entropic value are difficult to control. The states of manufacturing systems can be analyzed through their information entropy, but the complex traits of the structure and operation of manufacturing systems must be understood and grasped exactly. [10] summarized the meaning of Static (Structural) Entropy from an information-theoretic perspective way as:

$$H_s = -\sum_{k=1}^{m} \sum_{j=1}^{S_k} p_{kj} log p_{kj} \quad (3)$$

The structural entropy model is a structural measure created based on the schedule, which only considers the planned states at each resource. Eq. (3) can be applied to any entities within a system for which a schedule can be worked out, such as machines, people (i.e., schedulers and operators), and specific work centers-work-in-progress areas, materials, and interfaces. Furthermore, based on Eq. (3), the dynamic (operational) entropy of cellular manufacturing systems can be expressed as

$$H_d^{'} = -\sum_{j=1}^{S_i^{'}} p_{ij}^{'} log_2 p_{ij}^{'} \quad (4)$$

where $S_i^{'}$ is the actual number of states of resource *i* in the processing, and $p_{ij}^{'}$ is the probability of state *j* of resource *i* in the operation, with $1 \leq j \leq S_i^{'}$, and $\sum_{j=1}^{s_i^{'}} p_{ij}^{'}$

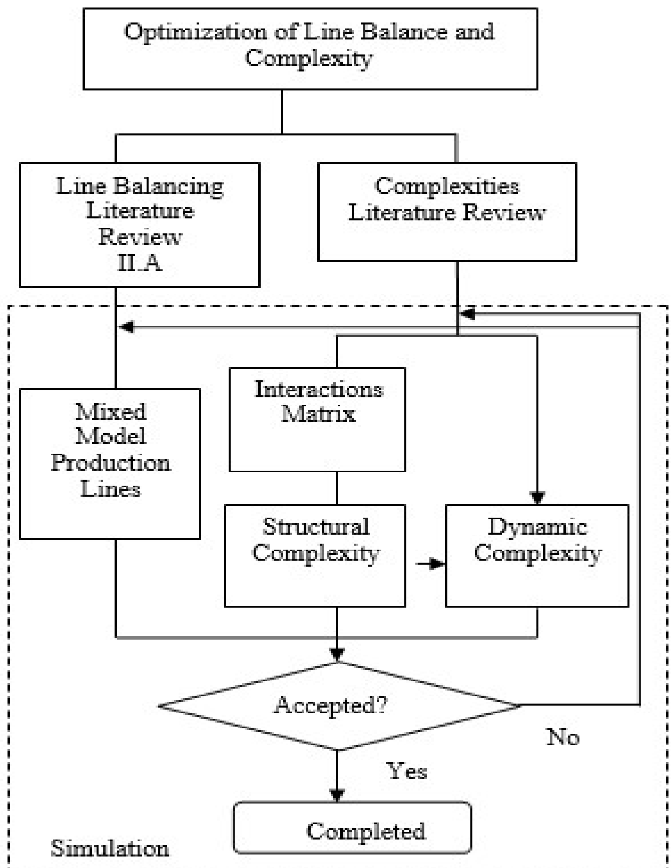

Fig. 1. Research framework

CASE STUDY WITH DATA SIMULATION

Line Balance of Mixed Model Line

Let us illustrate it with a simplified example. Consider the 3 electronics products: 1, 2, and 3 as shown in Figure 3 to Figure 5. Due to some final functionality differences, there are some minor differences in the processes, and also the sequence of assembly will be slightly different for each product. For example, consider the case of mounting the chassis as shown in Figure 2, the final mounting of the computer unit will affect the sequence of the processes and also the mounting time.

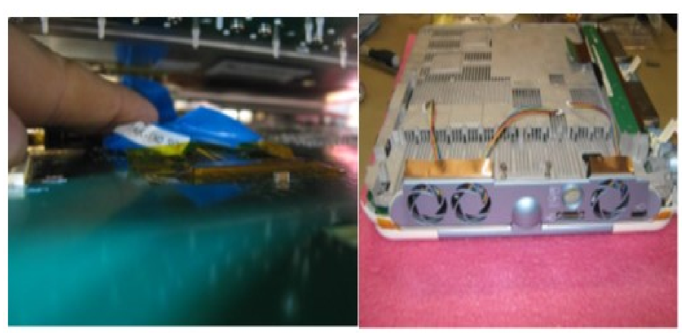

Fig. 2. Mounting of computer chassis

The precedence matrices for the three models are shown in Figure 3 to Figure 5.

Λ_1	1	2	3	4	5	6	7	8	9
1	1	0	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0
3	1	0	1	0	0	0	0	0	0
4	1	1	0	1	0	0	0	0	0
5	0	1	0	0	1	0	0	0	0
6	0	0	0	1	0	1	0	0	0
7	0	0	0	0	1	1	1	0	0
8	0	0	0	0	0	0	0	1	0
9	0	0	0	0	0	0	0	0	1

Fig. 3. Precedence matrix of product 1

Λ_2	1	2	3	4	5	6	7	8	9
1	1	0	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0
3	1	0	1	0	0	0	0	0	0
4	1	0	0	1	0	0	0	0	0
5	1	1	0	0	1	0	0	0	0
6	0	0	1	0	0	1	0	0	0
7	0	1	0	0	0	0	1	0	0
8	0	0	0	1	1	1	0	1	0
9	0	0	0	0	0	0	0	0	1

Fig. 4. Precedence matrix of product 2

Λ_3	1	2	3	4	5	6	7	8	9
1	1	0	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0
3	0	0	1	0	0	0	0	0	0
4	1	0	0	1	0	0	0	0	0
5	0	1	0	0	1	0	0	0	0
6	0	1	1	0	0	1	0	0	0
7	0	0	1	0	0	0	1	0	0
8	0	0	0	1	0	0	0	1	0
9	0	0	0	0	1	1	0	1	1

Fig. 5. Precedence matrix of product 3

With the framework provided, we have the result shown in Table 1 for the three products and two kinds of line balance. They differ in the way tasks are grouped in different terminals.

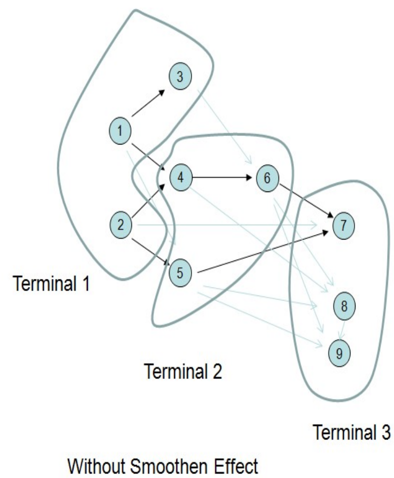

Fig. 6. Precedence diagram for without smoothen effect

The Not Smoothen Effect (Figure 6) is enhanced with Smoothen Effect 1 (Figure 7) in that the smoothness of the production improved from 114 minutes to 98 minutes. It is a measure of whether the production is still smooth if only one product is produced at a time. Also, the Structural and Dynamic Complexities can be calculated by applying Eq. (3) and (4). The Dynamic Complexities are also improved because Smoothen Effect 1 has a more rigid precedence relationship for the three tasks in Terminal 1.

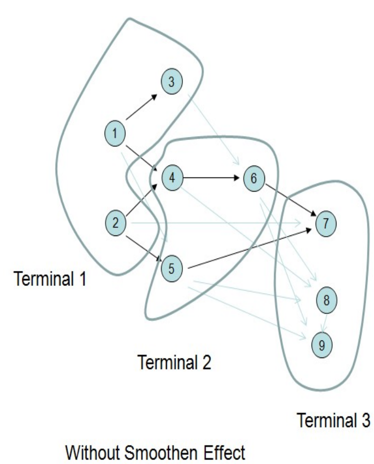

Fig. 7. Precedence diagram for with smoothen effect 1

DISCUSSION OF FINDINGS

Since the configuration for Terminal 3 is the same for Not Smoothen Effect and Smoothen Effect 1, they have the same Structural or Dynamic Complexities. However, there are improvements for Dynamic Complexity and Current Dynamic Complexity for Terminal 1. The precedence diagram of Termi-

TABLE 1
SUMMARY OF LINE BALANCE AND L COMPLEXITIES

Separated into 3 Terminals	Not Smoothened Effect				Smoothened Effect 1			
	Terminal 1	Terminal 2	Terminal 3	Overall	Terminal 1	Terminal 2	Terminal 3	Overall
Total Processing Time	156	193	146		166	183	146	
$\sum_{i=1}^{n}\sum_{j=1}^{J}\lvert P_j - P_{ij}\rvert$	19.00	46.00	49.00	114.00	19.00	30.00	49.00	98.00
Structural Complexity	1.52	1.50	1.24	4.26	1.40	1.48	1.24	4.13
Dynamic Complexity with Each Machine Down Each Day								
Dynamic Complexity	1.82	1.96	1.62	5.40	1.38	1.82	1.62	4.82
Control Dynamic Complexity	0.94	0.93	1.00	2.87	0.92	0.92	1.00	2.83
Current Dynamic Complexity	1.70	1.44	1.45	4.60	1.41	1.69	1.45	4.56

nal 1 for Not Smoothen Effect 1 is shown in Figure 6, while that for Smoothen Effect 1 is shown in Figure 7. The main difference is Task 4 can only start when both of the other Tasks (1 and 2) have completed. For the case of Not Smoothen Effect 1, it can be started as long as Task 1 has completed. When machine 1 has completed the work but machine 2 is down, production people can start Task 2 for the Not Smoothen Effect. In the case of Smoothen Effect 1, it is not possible to start Task 4. In other words, the production people can adjust the sequence of production and not follow the production schedule in the former situation. The Smoothen Effect 1 has an intrinsic added advantage that the cycle time for each product model is also smoothened. The more rigid requirement of Terminal 1 also affects Dynamic Complexities. For machines broken down for the whole day, the Dynamic Complexity is improved from 1.82 to 1.38, and the Current Dynamic Complexity is improved from 1.70 to 1.41. Both complexities will make the monitoring of the production schedule easier. However, Dynamic Complexity of Terminal 2 is not much affected. Terminal 2 has the work sequence where the final task can start when only one task is completed. Therefore, it suffers from the same problem of Terminal 1 of the original configuration.

Monitoring of production schedule is important for production planning people and sales team [11,12]. They can be more comfortable if they know that the actual production run is not much deviated from their planning or expectation [13]. However, the less rigid production sequence of the original Not Smoothened Effect will allow the production people to change the sequence of work according to their own idea if there is any production problem. The change of sequence is likely to happen as production department concerns more on manpower utilization. They do not want to have manpower idling, so they will readjust the work if there is anything wrong in the production including materials' shortage, machine breakdown or quality problem. This change of sequence can become a nightmare to the sales people, because the products manufactured are not needed in the market or customers. The management people will also be frustrated because there is over-production that becomes inventory cost.

This study is fundamentally different from the conventional line balancing optimization with the addition of complexity consideration to the efficiency of line balance. Traditionally, line balances only focus on shortening the cycle time or minimizing the manpower. Most important was to maximize productivity. But producing too many things is already found to be detrimental to a company if it is not saleable, as it creates inventory burden. To ensure actual production sequence to match closely with the original production planning, there is a need to control the sequence so that it cannot be changed easily. The complexity created is Dynamic Complexity, and there is always a limit that a company can afford. This study has quantified the Dynamic Complexity associated with a line balance production configuration. Therefore, it is no longer a subjective judgment but a objective index that the industrial engineers can measure. This study can help to measure whether a line balance can contribute a lean manufacturing and eliminate unnecessary inventory in actual production.

Previous line balancing only focused on improving tangible benefit, such as reducing manpower or reducing the cycle time. On the other hand, complexities' studies were only employed to depict the complexity of a schedule once it is formulated. This research provides a methodology to optimize a line balancing while considering the complexities (which are normally regarded as intangible) during the optimization process.

CONCLUSION AND RECOMMENDATIONS

A simulation exercise has been conducted to observe the Structural and Dynamic Complexity for two different kinds of line balance. While the Smoothen Effect has an intrinsic added advantage that the cycle time for each product model is also balanced, the process induced another advantage that the Control Dynamic and Current Dynamic Complexities are improved as well. A cost factor can be assigned to the complexities' measure and the line balance measure to find out the optimal value. However, optimization of line balance, with many tasks and other elements, is an NP-hard issue. A more efficient method such as Ant Colony Optimization, can be employed pragmatically to find a reasonable optimization.

Declaration of Conflicting Interests

This study possessed no known conflicts of interest.

REFERENCES

[1] N. T. Thomopoulos, "Mixed model line balancing with smoothed station assignments," *Management Science,* vol. 16, no. 9, pp. 593-603, 1970.

[2] J. I. Van Zante-de Fokkert and T. G. de Kok, "The mixed and multi model line balancing problem: A comparison," *European Journal of Operational Research,* vol. 100, no. 3, pp. 399-412, 1997.

[3] S. Z. Marvizadeh, "Entropy applications in industrial engineering," Doctoral dissertation, Department of Industrial and Management Systems Engineering, University of Nebraska-Lincoln, Lincoln, NE, 2013.

[4] G. Taguchi, *Taguchi Methods, Research and Development.* Bingham Farms, MI: American Supplier Institute Press, 1992.

[5] A. Al-Refaie, "Optimizing SMT performance using comparisons of efficiency between different systems technique in DEA," *IEEE Transactions on Electronics Packaging Manufacturing,* vol. 32, no. 4, pp. 256-264, 2009.

[6] R. H. Alamoudi, "Interaction based measure of manufacturing systems complexity and supply chain systems vulnerability using information entropy," Doctoral dissertation, University of Miami, Miami-Dade County, FL, 2008.

[7] A. V. Deshmukh, J. J. Talavage and M. M. Barash, "Complexity in manufacturing systems, Part 1: Analysis of static complexity," *IIE Transactions,* vol. 30, no. 7, pp. 645-655, 1998.

[8] S. Emde, N. Boysen and A. Scholl, "Balancing mixed-model assembly lines: A computational evaluation of objectives to smoothen workload," *International Journal of Production Research,* vol. 48, no. 11, pp. 3173-3191, 2010.

[9] C. E. Shannon, "A mathematical theory of communication, Part I, Part II," *Bell System Technical Journal,* vol. 27, pp. 623-656, 1948.

[10] Z. Zhang, "Manufacturing complexity and its measurement based on entropy models," *The International Journal of Advanced Manufacturing Technology,* vol. 62, no. 9, pp. 867-873, 2012.

[11] Z. Guo, E. Ngai, Yang, C., and Liang, X. "An RFID-based intelligent decision support system architecture for production monitoring and scheduling in a distributed manufacturing environment", *International journal of production economics*, vol. 159, pp. 16-28, 2015.

[12] A. Panda, J. Jurko, and I. Pandova, I. "Monitoring and Evaluation of Production Processes", *Springer International Publishing, Basel*, vol. 10, pp. 978-983, 2016.

[13] D. De-Felipe, and E. Benedito, "Monitoring high complex production processes using process capability indices", *The International Journal of Advanced Manufacturing Technology*, vol. 93, no. 1, pp. 1257-1267.

— This article does not have any appendix. —