International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:6, No:2, 2012

Performance Comparison of Two Assembly Line Concepts: Conveyor Line and Box Assembly Line

Kezia Amanda Kurniadi, Emre Islamoglu, and Kwangyeol Ryu

Abstract**—**As there has been a recognizable transition in automotive industry from mass production to mass customization, automobile manufacturers and their suppliers have been seeking ways for more flexible and efficient processes. Eventually, modular production is currently being applied to manage the changing orders of the industry. In this paper, two different modular assembly line concepts were studied: conveyor line and box assembly line. Mathematical model for two assembly line concepts were developed and their production line efficiency were compared as a performance measure to improve their assembly line balancing.

Keywords**—**Line Efficiency, Box assembly line, Conventional conveyor line

I. Introduction

DURING recent decade, a recognizable transition has been realized in automotive industry from mass production to mass customization. One of the main reasons behind this transition is increasingly complicated customer demand of highly diversified products[1]. As a result, automobile manufacturers and their suppliers have been seeking ways for more flexible and efficient production process.

Modules are perceived as an engineering tool to manage a complex product by dividing it into sub-assemblies[2]. Common modules used in automotive industry are cockpit, front-end, seat, door, fuel tank, etc[3]. In this paper, we studied about two different modular assembly concepts at different module suppliers: conveyor line and box assembly line. These two assembly concepts were analyzed and their mathematical models are created. Afterwards, we compared their respective production line efficiency as a performance measure for evaluation.

II. Related Works

A. Modularity and Synchronous Production

A common automotive assembly line allows automobile manufacturer to produce a large variety of different models on a single production line and therefore is a mixed model assembly line. *Kim and Jeong*[4] characterized mixed-model assembly line by their ability to assemble different models of products without holding large inventories. An automobile is composed of about 20,000 components[5].

Kezia Amanda Kurniadi is with Pusan National University, San 30 Jangjeon-dong, Geumjeong-gu, Busan 609-735, South Korea (e-mail: akkez@ pusan.ac.kr).

Emre Islamoglu is with Pusan National University, San 30, Jangjeon-dong, Geumjeong-gu, Busan 609-735, South Korea (e-mail: emre.islamoglu@ hbpogroup.com).

Kwangyeol Ryu is with Pusan National University, San 30, Jangjeon-dong, Geumjeong-gu, Busan 609-735, South Korea (e-mail: kyryu@ pusan.ac.kr).

Product modules offer manufacturers the ability of efficient mass customization by enabling the postponement of final assembly until customer orders are received[6]. Each module is assembled and delivered just in sequence to the final assembly line[7].

Synchronous production is an integrated supply chain approach which ensures product delivery that is defect-free and matches the exact requirement[8]. Obviously, production line of module suppliers are well synchronized to production line of customer so that there is a one-to-one correspondence between the products assembled in two lines[9].

B. Modular Assembly

Sako[10] picked modular strategies in product design and production as the recent focus of many OEM (Original Equipment Manufacturer) and suppliers. The long traditional assembly line is replaced by a modular, semi-autonomous assembly system based on shorter lines[11]. *Sako and Murray* [12] pointed out the influence of modularization on the factory floor as the ability to pre-combine a large number of components into modules and to be assembled off-line and then brought onto the main assembly line and incorporated through a small and simple series of tasks. It has always been easier to produce a complicated products by dividing the process into modules or cells[13]. Some basic characteristics of a modular assembly line can be defined by as below:

1) Synchronous production when customer call-off is realized
2) Delivery of the assembled modules in sequence within the given time frame
3) Assembly facility is usually located in a close proximity to the customer production line due to high transportation cost of the modules
4) Assembly facility designed to respond maximum capacity of the customer
5) Significant investment in information technologies to receive order, manage material flow, enable module assembly and sequential delivery
6) Assembly line flexibility is crucial since the line is designed to respond maximum capacity requirement of OEM regardless of average production rate

There are also potential benefits with modular production such as stability in demand and supply patterns, inventory reduction, elimination of demand amplification, and better long-term planning[14]. However, there is also a high pressure for delivering of the defect free parts to the end assembly line[15]. By utilizing modularity, automobile manufacturers shift some of their responsibilities to their suppliers. This shift requires suppliers to have quality performance above the manufacturer and with continuous improvement[16].

International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:6, No:2, 2012

III. Module Assembly Line Concepts

A. Conveyor Line (CL)

A conveyor system includes mechanical handling equipment that moves materials from one location to another. The first module supplier is using roller conveyor system. Conveyor line is divided into several assembly stations and the manning level for each station is one. When the call-off is realized by OEM, each assembly worker picks the component by the help of assembly securing system available. When the assembly is completed, the module is sent to the next station. This assembly concept is capable of producing a variety of different product models continuously in the same order without changing over between models. Part location is arranged according to the usage and component rate of each part that is assigned to be assembled at each station(See Fig. 1).

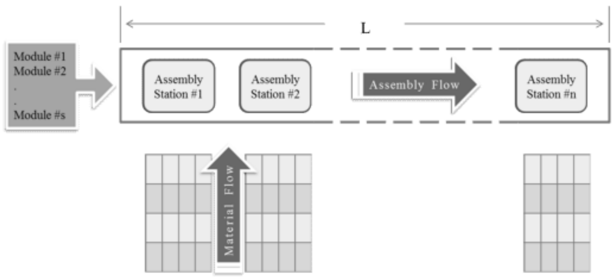

Fig. 1 Conveyor Line (CL) Layout

B. Box Assembly Line (BAL)

A box assembly line requires complete module assembly work done by one worker. When the call-off is done by OEM, a logistic worker picks up all components necessary, guided by picking system. The selected parts are gathered on a cart one by one and brought to an available assembly box. Otherwise, parts will be hold at a waiting area until an assembly box is available. When the assembly is completed, a final sequencing should be done to adjust the order of the module. The main assembly work is done by one worker completely, so the workers should be qualified and responsible for the job. Also there is a clear separation between part logistics and assembly operations(See Fig. 2).

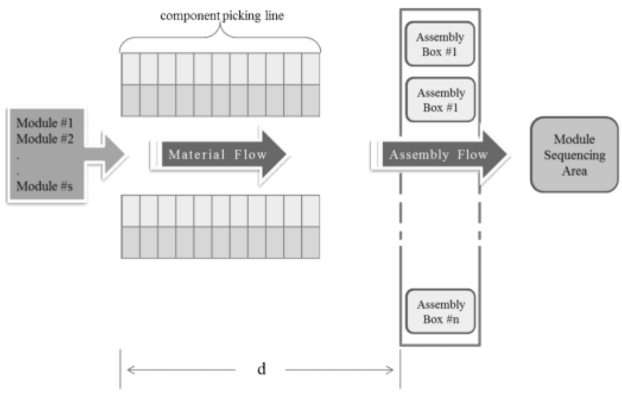

Fig. 2 Box Assembly Line (BAL)Layout

IV. Mathematical Model

A. Problem Definition

In this study, we studied and compared two different module suppliers with different modular assembly line concepts. One of the suppliers is using CL due to process requirements and layout constraints, while the other is using BAL since this concept is more suitable for their operation. The purpose of this study is to see which line concept gives the better line efficiency. The measure to evaluate two assembly concepts is the line efficiency as defined in (1):

$$Line\ Efficiency = \frac{\sum_{i=1}^{k} TW_i}{K \times TC} \times 100\%, \quad (1)$$

where, TW_i is total work time at station i, K is the number of workstations, and TC is cycle time of assembly line. Cycle time has to be reduced in order to get a bigger value of line efficiency that means the assembly line can produce more products.

B. Mathematical Model for CL

In case of CL, each component variant should be considered as a part of the assembly work. At this point, the term “component rate” is used to represent the frequency of a component being assembled considering all module variants demanded by OEM. To define total work time, following notations are used in this paper:

i: index of assembly stations ($1,2,\ldots,n$)
m: index of module variants ($1,2,\ldots,s$)
j: index of components ($1,2,\ldots,k$)
w_{ij}: assembly time of component j at station i (min)
p_{ij}: picking time of component j at station i (min)
u_j: usage of component j (for module m)
r_j: rate of component j (ratio of module variant where component j is assembled)
L: length of conveyor (m)
v_c: conveyor speed (m/min)

Assumptions for the conveyor line are as follows:

1) Manning level of each station is 1
2) Total work time at any station is less than demand rate to avoid waiting time between assembly stations
3) Uniform sequence and uniform demand rate are available from OEM

To determine the cycle time of conveyor line, we need to find the station with the longest work time. Total work time for a module m at station i is the sum of total assembly time (TA_{im}), total part picking time (TP_{im}), and total handling time (TH_{im}). Then we can easily state that:

$$TA_{im} = \sum_{j=1}^{k} \left(w_{ij} u_{ij} \right) \quad (2)$$

$$TP_{im} = \sum_{j=1}^{k} \left(p_{ij} u_{ij} \right) \quad (3)$$

$$TH_{im} = \frac{L}{n v_c} \quad (4)$$

Finally we get our total work time at station *i* for module *m* as in following equations:

$$TW_{im} = TA_{im} + TP_{im} + TH_{im} \quad (5)$$

$$TW_{im} = \sum_{j=1}^{k} \left(w_{ij} + p_{ij} \right) u_{ij} + \frac{L}{nv_c} \quad (6)$$

If a component is not assigned to be assembled at station *i*, then the picking time and assembly time becomes zero. When we consider the whole *s* module variants, total work time would be $\sum_{m=1}^{s}\sum_{i=1}^{n}\sum_{j=1}^{k}\left(w_{ij}+p_{ij}\right)u_{ij}$. Here the term component rate comes into our formulations. Then average total work time spent at assembly stations to produce one module becomes:

$$TW = \sum_{i=1}^{n} \sum_{j=1}^{k} \left(w_{ij} + p_{ij} \right) u_{ij} r_{ij} + \frac{L}{v_c} \quad (7)$$

C. Mathematical Model for BAL

In box assembly line, there is a fine line between component picking operations and assembly operations. When a module order is available from OEM, first corresponding components are picked from the shelves then these components are brought to an available assembly box for assembly. Therefore we should consider picking and assembly processes as separate operations while calculating total work time. To find total work time spent at this assembly line we used following notations:

i: index of assembly stations (*1,2,…,n*)
m: index for module variant (*1,2,…..,s*)
j: index for component (*1,2,…..,k*)
w_j: assembly time for component *j* (min)
p_j: picking time for component *j* (min)
u_j: usage of component *j* (for module *m*)
r_j: rate of component *j* (ratio of module variant where component *j* is assembled)
d: average distance from picking line to assembly box
v_w: labor walking speed (m/min)
t_s: sequencing time per module

Assumptions for the box assembly line are as follows:

1) Manning level of at each assembly box is 1
2) Uniform sequence and uniform demand rate are available from OEM
3) Sequencing time is equal for each module variant

After all the components are picked, they are brought to an available box assembly station. Total time spent for this transportation activity for *s* number of modules will be $2ds/v_w$. After parts transportation is done, worker at the assembly box starts working on the module and total time spent by all workers to assemble *s* modules is equal to $\sum_{m=1}^{s}\sum_{j=1}^{k} w_j u_j$. Then after assembly is completed, modules are released for sequencing job. Considering time t_s is spent per module to insert it in the right place. We can formulate TP_m, TA_m and TS_m as:

$$TP_m = \sum_{j=1}^{k} p_j u_j + \frac{2d}{v_w} \quad (8)$$

$$TA_m = \sum_{j=1}^{k} w_j u_j \quad (9)$$

$$TS_m = t_s \quad (10)$$

Therefore, total work times, *TW*, for module *m* is:

$$TW_m = TP_m + TA_m + TS_m \quad (11)$$

The average total work time spent to produce one module using component rate is:

$$TW = TW_m = \sum_{j=1}^{k} \left(p_j + w_j \right) u_j + \frac{2d}{v_w} + t_s \quad (12)$$

D. Comparison Analysis

We have calculated production line efficiency of CL and BAL for our comparison purposes. We can conclude that neglecting the different positioning time of two assembly line concepts, total time (T) to be spent on purely picking all the components and assembling them on the modules (i.e., T_{CL} and T_{BAL}) would be same. In other words;

$$T_{CL} = \sum_{i=1}^{n} \sum_{j=1}^{k} \left(w_{ij} + p_{ij} \right) u_j r_j \quad (13)$$

$$T_{BAL} = \sum_{j=1}^{k} \left(p_j + w_j \right) u_j r_j \quad (14)$$

V. Simulation Model

A. Sample Data

In order to simulate and compare line efficiency of two assembly line concepts, we created an initial example data that includes front-end module demand information from OEM. We have defined four vehicle options related with front-end module. By combining four characteristics, front-end module manufacturer is able to build sixteen different module variants which are shown in Table I including the module rate.

TABLE I
MODULE VARIANTS

Module Number	Module Rate (%)	Module Variant			
1	9.8	Diesel	Automatic	with AC	Domestic
2	18.2	Diesel	Automatic	with AC	Export
3	2.5	Diesel	Automatic	without AC	Domestic
4	4.6	Diesel	Automatic	without AC	Export
5	9.8	Diesel	Manual	with AC	Domestic
6	18.2	Diesel	Manual	with AC	Export
7	2.5	Diesel	Manual	without AC	Domestic
8	4.6	Diesel	Manual	without AC	Export
9	4.2	Gasoline	Automatic	with AC	Domestic
10	7.8	Gasoline	Automatic	with AC	Export
11	1.1	Gasoline	Automatic	without AC	Domestic
12	2.0	Gasoline	Automatic	without AC	Export
13	4.2	Gasoline	Manual	with AC	Domestic
14	7.8	Gasoline	Manual	with AC	Export
15	1.1	Gasoline	Manual	without AC	Domestic
16	2.0	Gasoline	Manual	without AC	Export

We simplify the total number of components, which is originally hundreds became only 34, as shown in Table II.

TABLE II
MODULE COMPONENTS

Component Number	Component Name	Component Usage (EA)	Component Rate (%)
1	Radiator Gasoline	1	30
2	Radiator Diesel	1	70
3	Mounting Rubber	2	100
4	Radiator Bracket	2	100
5	Airguide LH Gasoline	1	30
6	Airguide LH Diesel	1	70
7	Airguide RH Gasoline	1	30
8	Airguide RH Diesel	1	70
9	AT Oil Cooler	1	50
10	Condensor	1	80
11	Sealing Foam	3	80
12	Intercooler	1	70
13	Intercooler Hose	2	70
14	Hose Clamp	4	70
15	Intercooler Airguide LH	1	70
16	Intercooler Airguide RH	1	70
17	Fan Shroud Gasoline	1	30
18	Fan Shroud Diesel	1	70
19	Screw M8	4	70
20	Bolt M8	3	70
21	Nut M8	3	70
22	Screw M6	4	30
23	Bolt M6	3	30
24	Nut M6	3	30
25	Headlamp LH	1	100
26	Headlamp RH	1	100
27	Headlamp Bracket	2	100
28	Washer Tank	1	100
29	Horn High DOM	1	35
30	Horn Low DOM	1	35
31	Horn High EXP	1	65
32	Horn Low EXP	1	65
33	Bumper Beam	1	100
34	Front End Carrier	1	100

Demand rate in our simulation is 15 units per hour. Table III shows initial settings of conveyor line and box assembly line respectively.

TABLE III
ASSEMBLY LINE SETTINGS

Conveyor Line		
Conveyor length:	40	m
Conveyor speed:	40	m/min
Box Assembly Line		
Distance to assembly box:	80.0	m
Labor speed:	60.0	m/min
Module sequencing time:	1.8	min

B. Experiment Result

After defining the input parameters, we calculated the total work time spent by each assembly line concept by using Excel whose results are shown in Table IV and V. After finding total work time, we have calculated related line efficiency required to operate each line. Finally using work time, we compared labor productivity of each line.

TABLE IV
CONVEYOR LINE MODULE WORK TIME

Module Number	Processing Time (second)			
	Picking Time	Assembly Time	Handling Time	Total Time
1	274	1,080	60	1,414
2	274	1,080	60	1,414
3	252	996	60	1,308
4	252	996	60	1,308
5	264	1,044	60	1,368
6	264	1,044	60	1,368
7	242	960	60	1,262
8	242	960	60	1,262
9	220	768	60	1,048
10	220	768	60	1,048
11	198	684	60	942
12	198	684	60	942
13	210	732	60	1,002
14	210	732	60	1,002
15	188	648	60	896
16	188	648	60	896

TABLE V
BOX ASSEMBLY LINE MODULE WORK TIME

Module Number	Processing Time (second)				
	Picking Time	Assembly Time	Handling Time	Sequencing Time	Total Time
1	274	1,080	45	20	1,419
2	274	1,080	45	20	1,419
3	252	996	45	20	1,313
4	252	996	45	20	1,313
5	264	1,044	45	20	1,373
6	264	1,044	45	20	1,373
7	242	960	45	20	1,267
8	242	960	45	20	1,267
9	220	768	45	20	1,053
10	220	768	45	20	1,053
11	198	684	45	20	947
12	198	684	45	20	947
13	210	732	45	20	1,007
14	210	732	45	20	1,007
15	188	648	45	20	901
16	188	648	45	20	901

After defining the input parameters, we calculated the line efficiency for each module in each assembly line concept by using Excel whose results are shown in Table VI and the comparison results is shown in Fig. 3.

TABLE VI
LINE EFFICIENCY RESULTS

Module Number	Line Efficiency (%)	
	CL	BAL
1	43.64	32.85
2	43.64	32.85
3	43.78	32.96
4	43.78	32.96
5	43.68	32.88
6	43.68	32.88
7	43.82	32.99
8	43.82	32.99
9	45.49	34.28
10	45.49	34.28
11	45.91	34.61
12	45.91	34.61
13	45.63	34.39
14	45.63	34.39
15	46.09	34.76
16	46.09	34.76

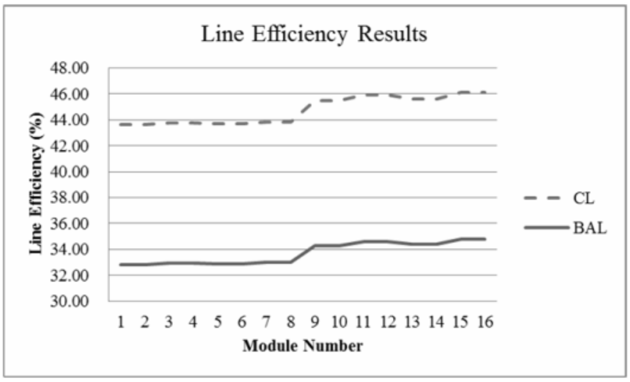

Fig. 3 Comparison of Line Efficiency between CL and BAL

VI. Conclusion

The brief simulation results showed us that production line efficiency of sixteen modules at CL has a bigger value than BAL. This difference happens because BAL has more processes and bigger value of total work time. This production line efficiency results can be a background for module suppliers to increase their assembly line balancing.

Assembly line balancing can be achieved by minimization of number of workstations, minimization of cycle time, minimization of smoothness in workload, and maximization of work relatedness. In BAL, the module sequencing job is done by one dedicated person. Depending on the delivery method, this job may require additional work force or job sharing that would obviously improve labor productivity.

In this study, we did not consider waiting time in the mathematical and simulation models. If a predefined waiting time is allowed, results for both line concepts might be different. We also did not use pervasive commercial simulation software in this research to discover plentiful comparison results on two assembly lines. These concerns are left to be investigated during a future research.

Acknowledgment

This research is supported by the *i*-Manufacturing projects funded by the Ministry of Knowledge Economy (MKE) of Korea, the authors would like to thank for their support.

References

[1] G. Chryssolouris, N. Papakostas, "A perspective on manufacturing strategy: produce more with less," *CIRP Journal Manufacturing Science and Technology*, vol. 1 iss. 1, pp. 42–52, Jan. 2008

[2] M. Sako, M. Warburton, "Modularization and outsourcing project, preliminary report of European research team," *prepared for the IMVP Annual Forum, Boston, MIT*, Oct. 1999.

[3] S. P. McAlinden, B. C. Smith, and B.F. Swiecki, "he future of modular automotive systems: where are the economic efficiencies in the modular assembly concept?," *Michigan Automotive Partnership Research Memorandum*, no. 1, Nov. 1999.

[4] S. Kim, B. Jeong, "Product sequencing problem in mixed-model assembly line to minimize unfinished works," *Computer and Industrial Engineering*, vol. 53 iss. 2, June 2007, pp. 206–214.

[5] D. Alford, P. Sackett, and G. Nelder, "Mass customization-an automotive perspective," Int J Prod Econ, vol. 65, Apr. 2000, pp. 740–741.

[6] P. Fredriksson, L. E. Gadde, "Flexibility and rigidity in customization and build-to-order production," *Science Direct Industrial Marketing Management*, vol. 34, pp. 695–705, May 2005.

[7] P. Frederiksson, "Modular assembly in the car industry—an analysis of organizational forms' influence on performance," *European Journal of Purchasing & Supply Management*, vol. 8, pp. 221–233, Des. 2002.

[8] D. Doran, "Manufacturing for synchronous supply: a case study of Ikeda Hoover Ltd," *Integrated Manufacturing Systems*, vol. 13 no. 1, pp. 18–24, Feb. 2002.

[9] J. A. Faria, "A canonical model for the analysis of manufacturing systems," in *Production Planning and Control*, vol. 19 no. 7, Des. 1994, pp. 632–644.

[10] Sako, M., "Modularity and outsourcing: The nature of co-evolution of product architecture and organization architecture in the global automotive industry", in Prencipe, A., Davies, A. and Hobday, M., The business of systems integration, *Oxford University Press, Oxford*, 2003, pp. 53-259

[11] J. Bukchin, E. M. Dar-El, and J. Rubinatoz, "Mixed model assembly line design in a make-to-order environment", *Computers and Industrial Engineering*, vol. 41, pp. 405-421, Feb. 2002.

[12] M. Sako, F. Murray, "Modules in design, production and use: implications for the global automotive industry," *paper presented at the International Motor Vehicle Program (IMVP) Annual Sponsors Meeting, Cambridge Massachusetts, USA*, Oct. 1999.

[13] C. Y. Baldwin, K. B. Clark, "Managing in the age of modularity," *Harvard Business Review*, vol. 75, 1997, pp. 84–93.

[14] E. Andrian, M. Coronado, and C. L. Andrew, "Investigating the implications of extending synchronized sequencing in automotive supply chains: the case of suppliers in the European automotive sector," *International Journal of Production Research*, vol. 46, no. 11, pp. 2867-2888, June 2008.

[15] A. Larsson, "The development and regional significance of the automotive industry: supplier parks in Western Europe," *International Journal of Urban and Regional Research*, vol. 26, Dec. 2002, pp. 767–784.

[16] F. Veloso, R. Kumar, "The automotive supply chain: global trends and Asian perspectives," *Asian Development Bank ERD Working Paper Series 3*, Jan. 2002.

Kezia Amanda Kurniadi is a master student of the Department of Industrial Engineering at Pusan National University, Busan, South Korea. She received her B.S. from the Department of Industrial Engineering at Petra Christian University, Indonesia, in 2011. Her research interests include manufacturing systems technologies and control theories, analysis and assessment of manufacturing data, data and process mining, etc. Her email address is akkez@pusan.ac.kr.

Emre Islamoglu is Ph.D student of the Department of Industrial Engineering at Pusan National University, Busan, South Korea. He received B.S. from the Department of Electronics at Middle East Technical University, Turkey, in 1997. And he received his MBA from the Department of Business Management at KDI School, Korea, in 2000. He is working at HBPO Group, Busan, South Korea, as a Program Manager. His email address is emre.islamoglu@hbpogroup.com.

Kwangyeol Ryu is an Assistant Professor of the Department of Industrial Engineering, Pusan National University (PNU), Busan, South Korea. He received his B.S., M.S., Ph.D. from Department of Industrial Engineering, POSTECH, Korea. His research interests include fractal-based approaches such as Fractal Manufacturing System (FrMS), Fractal-based Supply Chain Management (*f*SCM), fractal-based Virtual Enterprise (FrVE) as well as innovative manufacturing technologies such as e-Manufacturing, Product Lifecycle Management (PLM), and Next Generation Manufacturing. His email address is kyryu@pusan.ac.kr and web address is http://sis.ie.pusan.ac.kr.