Simulation Analysis for Assembly Line Workstation Layout: Case Study

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Abstract—**The paper explores the cost saving projects that have been implemented in an electrical product assembly line, so called subwoofer speaker. Observation has been conducted on 26 workstations in an assembly line. Group discussion, real time study and simulation analysis have been performed to reduce operational cost. The result shows that the proposed layout was improved 22.68% space utilization in the production area which representing 0.56 percent of production rate. The simulation result gave the production personnel to decide the best improvement workstation layout and enhance the participation of employee in cost saving activities while improve production capacity.**

Keywords—modelling and simulation; production layout; assembly line

I. INTRODUCTION

MANY researchers and practitioners had explored the effectiveness as well as the utility of production system to enhance the production productivity through strengthen the workstation. There are a lot of issues had been rising and until today, redevelopment of the production system is still having a space to improve due to the need and significant role in the industry.

From the study, the authors identified that most researchers used to study on demand uncertainty in production line. The researchers used simulation to predict demand uncertainty based on fluctuated order from customers and increasing number of competitors that offer similar products and services. Ashayeri and Lemmes [1] proved that the value of system dynamic simulation in a real-life setting as an indispensable tool. Reiner and Trcka [2] initiated that the improvement and simulation model developed to allow further research on the analysis of supply chains and suggest that universally valid statements based on the behaviour of specific supply chains can be quite doubtful. Besides, Er and MacCarthy [3] identified that increasing the level of product variety has a detrimental impact on production line performance. In the presence of supply lead-time and demand uncertainty, high levels of variety result in much longer flow time and much higher system inventory relative to more stable conditions. The impact is greatest when variety involves critical materials which are required early in the production process and entail long set-up times. Krajewski and Ritzman [4] stated that demand is used as a main key element in calculating the economic order quantity (EOQ) to minimise the total of holding inventory and ordering costs.

For Mahmood, et. al. [5], managing inventory is one of the essential concerns in the lean production system implementation. The issue of inventory management was fascinated some researchers to use simulation in operation research. It is said that the ultimate goal of any effective production system is to reduce inventory (with the assumption that products are available when needed) [6].

Petrovic [39] found that uncertainty in customer demand, external supplier reliability and lead times to inventories in a serial production, supply chain (SC) can be effectively described by fuzzy sets. In contrast, the results of Fleisch and Tellkamp [7] indicate that eliminating inventory inaccuracy can reduce supply chain cost as well as reduce the level of

Article history: Manuscript received 14 February 2019; received in revised form 6 April 2019; Accepted 8 April 2019.

out-of-stock, even if the level of process quality, stolen and unsaleable items remains unchanged. Tannock et. al. [8] suggest that data-driven simulation can be useful to support the design and improvement of supply chains especially in managing inventory.

On the other hand, the researchers used to study the optimizing lead time in operation lines using simulation. Persson and Olhager [9], was identified an alternative supply chain design with respect to quality, lead-times and costs, meanwhile O'kane [10] studied the impact of adding new machines to the existing layout in optimising lead time. Moreover, the results of the simulation show that the revised process, sheeting by combining paper of all grades with same size to cut at a sheet cutter, gives a better outcome in terms of productivity, cost saving and efficiency, than that of the original process [11]. The process improvement can be effectively accomplished with an integrated approach of using proposed computer based tools. Nevertheless, Ozbayrak et. al. [12] found that the modelling effort has focused on measuring the production system performance in terms of key metrics such as inventory, WIP levels, backlogged order, and customer satisfaction.

Subsequently, the simulation is able to allocate the operator's assembly operations into a parallel machine-scheduling problem with precedence constraints using the objective of minimizing the work flow among the operators [13]. It allowed the management to predict if line-balancing strategies such as set-up reduction and parts sequencing would be sufficient, or if more fundamental changes such as the addition of lines or the replacement of machines was required [14]. However, the enlargement of the domain of application and consequently, enrichment of the simulation model by incorporating other types of resources and by considering resource reliability and routing flexibility [15].

In addition, the enrichment of the reasoning mechanism by incorporating new knowledge acquired from sets of planning simulations and investigation of the approach robustness and applicability in various scenarios.Thus, the main objective of this article is to deploy modelling and simulation approach in an electrical product for cost saving projects. The analysis were also based on lean production concepts in improving workstation layout. Section 2 will present the reseach methods, and followed by results in section 3. Finally, the discussion and conclusion were described in section 4.

II. RESEARCH METHODS

The study involved observation, group discussion, real-time study and action research on the selected assembly line was performed as shown in the Fig. 1 (see APPENDIX). The assembly line performs the assembly in two different types of products where both products were assembled at different assembly line at the inspection station. Both of the products were paired together, Product X going through nine workstations (WS1 – WS9), five inspection stations (WS10 – WS14) and adopted by another four sub-assembly workstations (WS15 – WS18) meanwhile Product Y was going through of three workstations (WS 19 –WS21) and one inspection station (WS22). Both products were paired (WS23) and inspected for final checking (WS24 – WS25) before it's entering the packaging station (WS26).

Table I shows the mean cycle time (from time study) and the distribution coefficient, which had been analysed by Input Analyser. The Input Analyser is a standard component provided in the ARENA software. The function of the input analyser itself is to identify the quality of fits of the distribution function of the input data station. The data show the result on the histogram chart where from there, the function such as a specific distribution function of the data allows comparing the distribution and showing the effect of the changes in parameter on the same distribution. Based on the trials data of each of the station, the input analyser can be made to show the changes of the parameter in each of the stations between the distributions, the statistic test of the chart. Trials of data were important to the input analyser, because the more the trials data, the better distribution it will. Total lead time for the single pairing product is 2218.1 seconds and required 443,620 seconds or 7393.67 minutes to complete 200 unit daily demands.

TABLE I. CYCLE TIME DISTRIBUTION ANALYSIS

WS	Mean (in second)	CT Distribution	Square Errors
WS1	75.8	75.1 + 1.45 * BETA(1.43, 1.63)	0.018456
WS2	85.7	84 + 2.96 * BETA(1.17, 0.951)	0.018570
WS3	176.0	TRIA(173, 176, 177)	0.100998
WS4	146.0	143 + 5.72 * BETA(1.07, 0.9)	0.056070
WS5	88.5	85 + 6 * BETA(0.991, 0.708)	0.008087
WS6	83.8	82.1 + LOGN(1.75, 1.44)	0.011701
WS7	112.0	110 + LOGN(1.93, 1.3)	0.019281
WS8	113.0	109 + 7 * BETA(0.893, 0.848)	0.057365
WS9	86.3	TRIA(83.1, 87.1, 88.8)	0.013379
WS10	69.1	66 + 5 * BETA(0.835, 0.525)	0.044335
WS11	71.8	TRIA(70.3, 70.6, 74.5)	0.004522
WS12	88.6	85 + 6 * BETA(1.1, 0.777)	0.022879
WS13	75.5	UNIF(73, 78)	0.020000
WS14	85.1	NORM(85.1, 1.39)	0.027741
WS15	73.1	71 + GAMM(0.989, 2.11)	0.047108
WS16	82.2	UNIF(80, 84)	0.080000
WS17	86.7	TRIA(83.2, 88, 89)	0.050658
WS18	58.6	56.3 + LOGN(2.45, 1.83)	0.061772
WS19	62.4	58.1 + 6.84 * BETA(1.86, 1.18)	0.062194
WS20	88.6	85 + ERLA(1.79, 2)	0.040622
WS21	70.4	TRIA(68, 70.4, 73)	0.090324
WS22	84.3	83.1 + 2.53 * BETA(1.3, 1.45)	0.007049
WS23	80.9	79.6 + ERLA(0.41, 3)	0.017899
WS24	62.3	NORM(62.3, 0.659)	0.014317
WS25	41.7	TRIA(40.7, 41.2, 43.3)	0.029892
WS26	69.7	64 + 8 * BETA(0.646, 0.347)	0.044358
Lead time	2218.1		

III. RESULTS

From observation and group discussion with production line personnel, the usage current layout was considered beyond the capacity (as Fig.1). Besides, the assembly line required operators employ unnecessary time for taking material from previous process and passing the work in progress product to the next station. Motion lost by the operator, the operator needs to take the set and walk to their station to begin assembling. In addition, the material handling or inventory are too messy and not suit lead to problem on sending inventory and material for assembly were not enough caused the assembly process delay. The production line was too long, there were unnecessary table placed in the line make the line longer.

After considering the above factors and other constraints such several operators who only skilled at using a certain machine and each of the operators have an approval tag as evidence that the operator itself skilled at certain station for handling certain equipment, proposed layout is determined as in Fig. 2 (see APPENDIX). As can be seen in Fig. 1, there are several strategies had been identified, including minimise working space, remove backward conveyor, applying one-piece flow production line, and relocating buffer for WIP material handling. The proposed layout may improve at least six workstations; WS3, WS11, WS14, WS18, WS22 and WS23 with specific improvement ratio. Table II shows new comparative cycle time distribution analyses (current vs. proposed layout). Based on the analysis, the proposed layout was improved at least 22.68% space utilisation in the production area. In other word, the manufacturing company has additional 22.68 % production capacity.

The simulation model was developed based on Fig. 1. Each workstation (WS) required at least one operator to do the assembly job. All of the operators work daily from 8:00 a.m. to 5:30 p.m. with an hour break between 9:30 a.m. and 10:00 a.m., one hour lunch break from 1:00 p.m. to 2:00 p.m., and 30 minutes' tea break after 3:30 p.m. The overtime was allowed but not more than two hours.

Fig. 2 shows a simulation model for the current layout with 26 workstations. There were two parts required to assemble in an assembly line. At this time, WS19 to WS22 were prepare part X before delivering to WS23 for main assembly preparation. WS23 was also considered pre-assembly workstation between part X and Y. This was the bottleneck area because the workstation received both part X and Y at the same time. However, the simulation model assumes that no bottleneck in WS 22 while W19 to WS 21 were not included in the modelling phase. The next process in WS24 to WS26 were involved the main assembly operation and final packaging. The scope of simulation model was ended at the point.

TABLE II. NEW CYCLE TIME DISTRIBUTION ANALYSIS (CURRENT VS PROPOSED LAYOUT)

WS	Improvement Ratio	CT Distribution (Proposed Layout)
WS3	1:3	TRIA(173, 175, 176)
WS11	1:1.5	68 + WEIB(1.6, 1.47)
WS14	1:5	NORM(82.5, 1.37)
WS18	1:1.5	55.5 + LOGN(2.41, 1.83)
WS22	1:7	77 + 1.79 * BETA(0.9, 0.7)
WS23	1:1.2	79.2 + GAMM(0.386, 3.19)

The improvement strategies were based on the reduction time by reducing the gap of material transportation. Improvement ratio as in Table III was considered in the simulation model. The simulation result for 8 hours operation is shown in Table III. The proposed layout is able to improve at least 0.56 percent of production rate. The simulation result gave the production personnel to decide the best improvement workstation layout. Investment cost and time to prepare the new layout influenced the manager to re-consider the improvement methods.

Table IV compares both current layout and proposed layout performances by a number of works in progress and manpower utilisation in every 26 workstations. Meanwhile, Fig. 3 shows manpower utilisation analysis between two different types of layout. Based on Table IV and Fig. 3, it was found that the proposed layout reduced the utilisation of manpower while improving the number of works in progress especially at WS3.

TABLE III. INPUT AND OUTPUT ANALYSIS

TABLE IV.	Current layout	Proposed Layout	Improvement Rate
Input	180	180	1/180*100 = 0.56%
WIP	37	36	
Output	143	144	

TABLE IV. WIP AND MANPOWER UTILISATION ANALYSIS

	Current layout		Proposed layout			Current layout		Proposed layout	
	WIP	MU(%)	WIP	MU(%)		WIP	MU(%)	WIP	MU(%)
WS1	-	39.86	-	39.91	WS13	1	32.45	-	32.67
WS2	-	45.12	-	45.08	WS14	-	36.48	1	35.52
WS3	27	78.47	21	78.47	WS15	1	31.32	-	31.35
WS4	1	64.97	1	65.30	WS16	-	35.07	1	35.28
WS5	1	39.15	-	39.37	WS17	1	36.95	-	37.00
WS6	-	37.02	1	37.30	WS18	-	24.96	-	24.73
WS7	1	49.21	-	49.55	WS22	-	35.74	1	33.15
WS8	-	49.41	1	49.43	WS23	1	34.02	-	34.04
WS9	1	37.62	-	37.85	WS24	-	26.28	1	26.34
WS10	-	30.07	1	30.20	WS25	-	17.60	-	17.57
WS11	1	31.09	-	30.25	WS26	1	28.99	-	29.02
WS12	-	38.29	1	38.49	Total	37	-	36	-

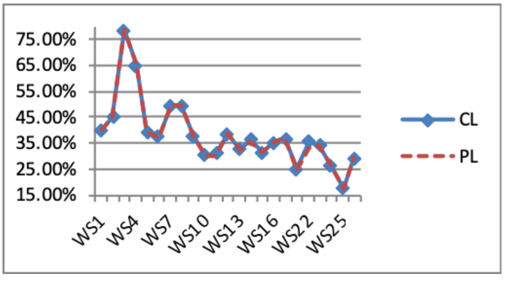

Fig. 3. Manpower utilisation comparison analysis.

Table V shows an efficiency measure for improving workstation layout based on discussion outcome with production line personnel. New proposed layout was able to improve 22.68 percent space utilisation. However, for output and WIP only 0.56 percent were able to count for efficiency measure. In other words, the proposed layout showed the very less impact to the productivity. Compared to using time saving tricks as proposed by Das et. al. [16], without new layout the production line was still able to meet quantity demand within takt time.

TABLE V. EFFICIENCY MEASURE FOR IMPROVING WORKSTATION LAYOUT

	Space utilisation	**Output**	**WIP**
Efficiency measure	22.68%	144/180 ~ 80%	0.56%

IV. DISCUSSION AND CONCLUSIONS

In summary, the paper has explained that workstation layout improvement strategies can be implemented in many efforts. There are no specific ways, but required the organization to define the best towards productivity improvement especially in reducing workspace capacity utilization. Meanwhile, the simulation test was used to validate the predetermined layout that can be implemented in achieving a better productivity performance.

Although the results show that there are small impact on productivity rate, the analysis proved that new layout had a chance to reduce the number of work-in-progress especially in WS3. Moreover, the most obvious finding to emerge from the analysis is that the improvement of workstation layout is significant with effective layout. The focus of improvement is to minimize the imbalance between man and machine while meeting a required output from the production line. Aghazadeh et. al. [17] mentioned that to improve workstation layout is being one of the important strategies as steps for cost reduction and standardization. Many firms started to re-organise about the production layout to reduce the cost and time, hence growth the number of outputs [18]. However, some literature studies found that there are a few things that need to take into consideration such as the number of product, model, the line balance, the automation used in the line, the flow of work piece throughout every station, the complexity of the production environment [19-21].

Shigematsu et. al. [22] identified that layout configuration is a timeless challenge for all firms due to technological change, unpredictable demand, and complex working environment. Nevertheless, the firm must determine the best alternative to cope with latest product demand and not fix the facts to improve the layout up-to-date. The commitment of top management and the readiness of all employees to recognize the appropriate solution were the key success factor for effective layout configuration because every change may require additional cost and critical decision making.

On the other hands, an effective layout is significant with material flow and space utilization [23]. Asef-Vaziri and Kazemi [24] mentioned that the movement of material is influenced by the production layout. It consists of the types of material handling and the transportation inside the factory. However, Caputo et. al. [25] stated that the material flow must consider occupational safety and health for man, machine and inventories.

For space utilisation, Gerald et. al. [26] revealed that the firms are currently having limited space and require them to maximise the facility layout. Mirko et. al. [27] found that to optimise the capacity firms must utilise all work space, including the upper position of building capacity especially small medium enterprise in particular factory lot. Administration office, miscellaneous items store, or light materials were suggested to be placed at upper side while the substantial machine or equipment utilises the ground space. The configuration was a proven arrangement for material flow, including incoming and outgoing material which involved third parties firm.

Next, minimizing the number of workstations was acknowledged as a parameter for workspace optimisation. There are several methods achieved to make the workstation minimization such as multitasking job by employees [26], subcontract item from third party firms [2], the use of automation machinery [22], the use of conveyor [28] and the integrated product design [29]. Wei et. al. [30] mentioned that firms have no specific approach to determine the most effective workstation towards cost effective. However, Sodhi and Tang [31] summarised that firms have no preference when producing own products due to specific process that asked by the customer. Although, the firms can suggest a win-win decision basis when expanding business operation with other customers.

Last but not least, workspace optmisation can be achieved by simplifying the operation procedure. The organised workspace can help to get rid of wasted time, especially in recovering the equipment. This consequently will expedite the processing time [32,33]. It will also subsequently increase the safety and the focus of workers when performing the work, hence the production of defective products can be avoided or reduced [34]. This will eliminate inefficiency in hiring the workers, which subsequently cause a substantial impact on the higher additional costs. As well, it will enhance the manufacturing flexibility and simultaneously moves the inventory and storage level in the work area [35]. This consequently allows the materials needed to be placed closer to the production line. It subsequently enables manufacturers to plan the right volume of buffer in the output line that consequently makes the production job can go smoothly without any disruptions due to supply issues [36]. As a result, products can be quickly made and sent out to customers within the stipulated time at high service levels [37,38]. For future study, the authors will include the result of the study in the simulation model to identify the other significance of the lead time reduction strategies as total towards workstation layout improvement.

APPENDIX

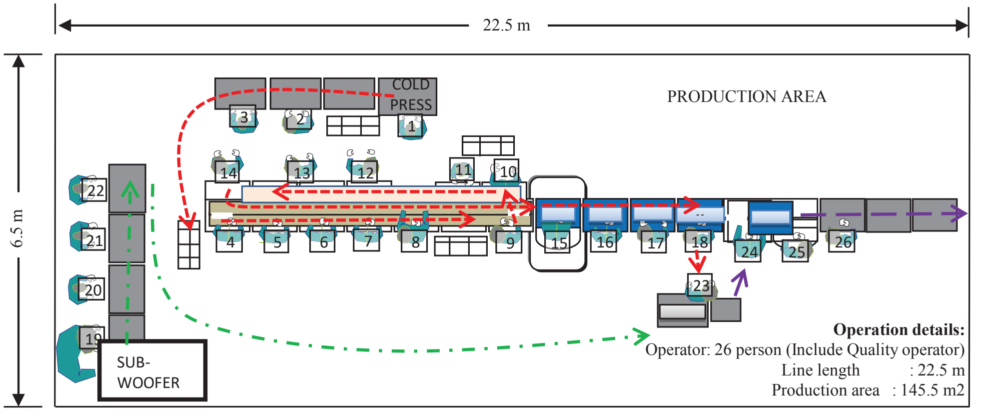

Fig. 1. General layout of an assembly line

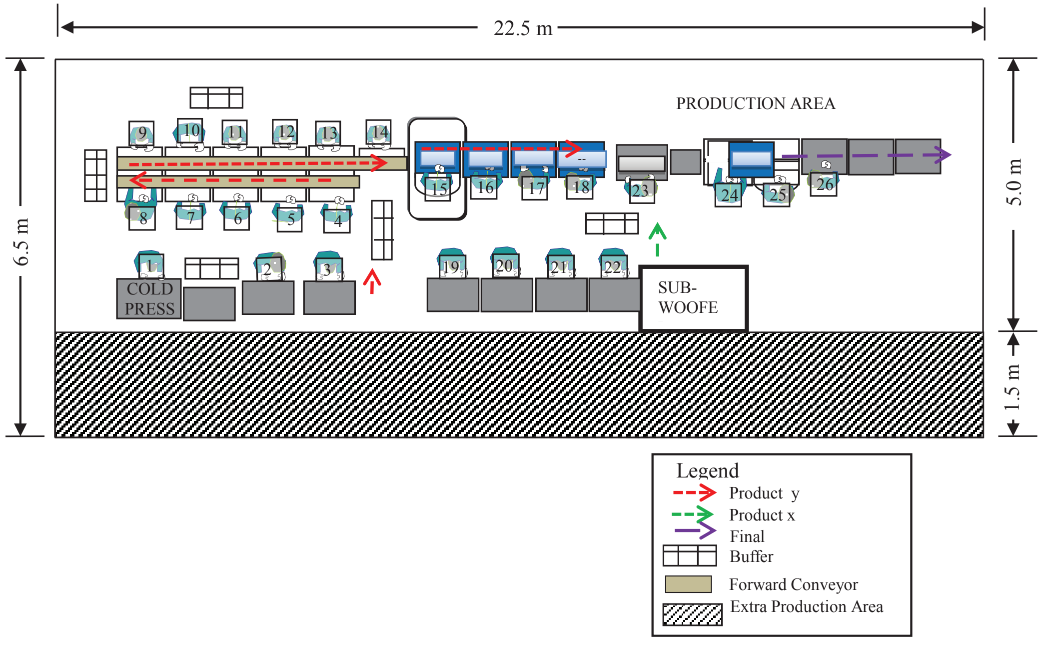

Fig. 2. Proposed layout of an assembly line

ACKNOWLEDGMENT

This research was supported by Universiti Malaysia Pahang and Ministry of Education for MyBrain15 programme.

REFERENCES

[1] J. Ashayeri and L. Lemmes, "Economic value added of supply chain demand planning: a system dynamics simulation", Robotic and Computer Integrated Manufacturing, vol. 22, pp. 550 – 556, 2006.

[2] G. Reiner and M. Trcka, "Customised supply chain design: problems and alternatives for a production company in the food industry: a simulation based analysis", International Journal of Production Economics, vol. 89, pp. 217 – 229, 2004.

[3] M. Er and B. MacCarthy, "Managing product variety in multinational corporation supply chain: a simulation study", Journal of Manufacturing Technology Management, vol. 17, no. 8, pp. 1117 – 1138, 2006.

[4] L.J. Krajewski and L.P. Ritzman, Operation Management Strategy and Analysis: Fifth Edition, Addison Wesley Publishing: United States of America, 1999.

[5] W.H.W. Mahmood, M.N.A. Rahman, B.M. Deros, K. Jusoff, A. Saptari, Z. Ebrahim, A.A.M. Sultan, M.H.A. Bakar, Sivarao and Z. Jano, "Manufacturing performance in greening supply chain management, special issue of engineering and technology, WASJ, vol. 21. pp.76-84, 2013.

[6] M.Z. Yusup, W.H.W. Mahmood, M.R. Salleh, M.R. Muhamad and A. Saptari, "Synthesizing the domain of lean practices in manufacturing operations: a review", Jurnal Teknologi, vol. 77, no. 1, pp. 153–162. 2015.

[7] E. Fleisch and C. Tellkamp, "Inventory inaccuracy and supply chain performance: a simulation study of a retail supply chain", International Journal of Production Economics, vol. 95, pp. 373 – 385, 2005.

[8] J. Tannock, B. Cao, R. Farr and M. Byrne, "Data-driven simulation of the supply chain –insights from the aerospace sector", International Journal of Production Economics, vol. 110, pp. 70-84, 2007.

[9] F. Persson, and J. Olhager, "Performance simulation of supply chain designs", International Journal of Production Economics, vol. 77, pp. 231 – 245, 2002.

[10] J. O'Kane, "Simulating production performance: cross case analysis and policy implications", Industrial Management & Data Systems, vol. 4, pp. 309 – 321, 2004.

[11] S. Kumar and P. Phrommathed, "Improving a manufacturing process by mapping and simulation of critical operations", Journal of Manufacturing Technology Management, vol. 17, no. 1, pp. 104 – 132, 2006.

[12] M. Ozbayrak, T.C. Papadopoulou and M. Akgun, "System dynamics modeling of a manufacturing supply chain system", Simulation Modeling Practice and Theory, vol. 15, pp. 1338 – 1355, 2007.

[13] S. Rajakumar, V.P. Arunachalam and Selladurai, "Simulation of workflow balancing in assembly shop-floor operations", Journal of Manufacturing Technology Management, vol. 16, no. 3, pp. 265 – 281, 2005.

[14] A. Greasley, "The case for the organizational use of simulation", Journal of Manufacturing Technology Management, vol. 15, no. 7, pp. 560 – 566, 2004.

[15] Wassim Masmoudi, Hedi Chtourou and Aref Y. Maalej. "A simulation-expert-system-based approach for machine sizing of production systems", Journal of Manufacturing Technology Management, vol. 17, no. 2, pp. 187 – 198, 2006.

[16] B. Das, J.M. Sanchez-Rivas, A. Garcia-Diaz and C.A. MacDonald, "A computer simulation approach to evaluating assembly line balancing with variable operation times", Journal of Manufacturing Technology Management, vol. 21, no. 7, pp. 872 – 887, 2010.

[17] S-M., Aghazadeh, S. Hafeznezami, L. Najjar and Z. Huq, "The influence of work-cells and facility layout on the manufacturing efficiency", Journal of Facilities Management, vol. 9 no. 3, pp.213-224, 2011.

[18] M.T. Gonçalves and K. Salonitis, "Lean assessment tool for workstation design of assembly lines", Procedia CIRP, vol. 60, pp. 386-391, 2017.

[19] F. Aqlan, S.S. Lam and S. Ramakrishnan, "An integrated simulation–optimization study for consolidating production lines in a configure-to-order production environment", International Journal of Production Economics, vol. 148, pp. 51-61, 2014.

[20] Mashitah Mohamed Esa, Nor Azian Abdul Rahman and Maizurah Jamaludin, "Reducing high setup time in assembly line: a case study of automotive manufacturing company in malaysia", Procedia - Social and Behavioral Sciences, vol. 211, pp 215-220, 2015.

[21] T. Koltai, N. Kalló and R. Györkös, "Calculation of the throughput-time in simple assembly lines with learning effect", IFAC-PapersOnLine, vol. 48no. 3, pp. 314-319, 2015.

[22] K. Shigematsu, Y. Yamazaki, S. Kato, F. Kojima and S. Takata, "Process-independent workstation layout for lean automation", CIRP Annals, vol. 67, no. 1, pp. 475-478, 2018.

[23] S. Kang and J. Chae, "Harmony search for the layout design of an unequal area facility", Expert Systems with Applications, vol. 79, pp. 269-281, 2017.

[24] A. Asef-Vaziri and M. Kazemi, "Covering and connectivity constraints in loop-based formulation of material flow network design in facility layout, European Journal of Operational Research, vol. 264, no. 3, pp. 1033-1044, 2018.

[25] A.C., Caputo, P.M., Pelagagge, M. Palumbo and P. Salini, "Safety-based process plant layout using genetic algorithm", Journal of Loss Prevention in the Process Industries, vol. 34, pp. 139-150, 2015.

[26] R.A. Gerald, R.O. John and J.S Marc, "U-shaped assembly line layouts and their impact on labour productivity: an experimental study", European Journal of Operational Research, vol. 156, pp. 698-711, 2004.

[27] F. Mirko, B. Simon, K. Simon, B. Joze, B. Miran, and P. Ivo, "Intelligent design of an unconstrained layout for a flexible manufacturing system", Neurocomputing, vol. 73, pp. 639-647, 2010.

[28] B.A. Kotzur, R.J. Berry, S. Zigan, P. García-Triñanes and M.S.A. Bradley, "Particle attrition mechanisms, their characterisation, and application to horizontal lean phase pneumatic conveying systems: A review", Powder Technology, vol. 334, pp. 76-105, 2018.

[29] T. Bortolotti, S. Boscari and P. Danese, "Successful lean implementation: organizational culture and soft lean practices", International Journal of Production Economics, vol. 160, pp. 182 – 201, 2015.

[30] Z. Wei, X. Song and D. Wang, "Manufacturing flexibility, business model design, and firm performance", International Journal of Production Economics, vol. 193, pp. 87 – 97, 2017.

[31] M.S. Sodhi and C.S. Tang, "Strategies and tactics of Chinese contract manufacturers and western OEMs (2001–2011)", International Journal of Production Economics, vol. 146, no. 1, pp. 14-24, 2013.

[32] M.P. Pe´rez and A.M. Sa´nchez, "Lean production and supplier relations : a survey of practices in the aragonese automotive industry", Technovation, vol. 20, 665 – 676, 2000.

[33] R. Shah and P.T. Ward, "Defining and developing measures of lean production", Journal of Operations Management, vol. 25, no. 4, pp. 785 – 805, 2007.

[34] M.A. Marhani, A. Jaapar and N.A.A. Bari, "Lean construction: towards enhancing sustainable construction in malaysia", Procedia - Social and Behavioral Sciences, vol. 68, pp. 87 – 98, 2012.

[35] E. Sundin, M. Björkman, M. Eklund, J. Eklund and I. Engkvist, "Improving the layout of recycling centres by use of lean production principles", Waste Management, vol. 31, no. 6, 1121 – 1132, 2011.

[36] G.N. Nyaga, J.M. Whipple and D.F Lynch, "Examining supply chain relationships: do buyer and supplier perspectives on collaborative relationships differ?", Journal of Operations Management, vol. 28, no. 2, pp. 101 – 114, 2010.

[37] M. Houshmand and B. Jamshidnezhad, "An extended model of design process of lean production systems by means of process variables", Robotics and Computer-Integrated Manufacturing, vol. 22, no. 1, pp. 1 – 16, 2006.

[38] J. Váncza, L. Monostori, D. Lutters, S.R. Kumara, M. Tseng, P. Valckenaers and H. Van Brussel, "Cooperative and responsive manufacturing enterprises", CIRP Annals - Manufacturing Technology, vol. 60, no. 2, pp. 797 – 820, 2011.

[39] D. Petrovic, "Simulation of supply chain behavior and performance in an uncertain environment", International Journal of Production Economics, vol. 71, pp. 429 – 438, 2001.