A Comparative Study Of U-Shaped Assembly System And Straight-Line Assembly System In Terms Of Cycle Rate And Efficiency By Using Delmia Quest Simulation

Siti Norhafiza Binti Abdul Razak[1], Imran Adil Bin Adnan[2]

[1,2]Universiti Kuala Lumpur Malaysia France Institute, Section 14, 43650, Bandar Baru Bangi, Selangor

e-mail: [1]sitinorhafiza@unikl.edu.my

Abstract

Since the progression of Industrial Revolution 4.0 (IR4.0), most machines in the assembly and production line have transformed into automated system and can be wirelessly controlled. In an Automated Assembly Line System (AALS), there are many different physical systems, classified according to its configurations. The two most used Automated Assembly Line Systems are U-Shaped Assembly System(USAS) and Straight-Line Assembly System(SLAS). Both configurations come with their own advantages and disadvantages which needs to be considered when designing an automated assembly line system. However, no empirical or experimental research has been done on the effects of using U-Shaped Assembly System compared to Straight-Line Assembly System in terms of Cycle Rate, Rc and overall system Efficiency, E. Therefore, this study aims to analyse and compare the two most used assembly line configurations. The analysis and comparison are achieved through findings from Microsoft Excel Calculations and simulation in Delmia Quest. The study attempts to choose the best assembly line configurations, examined in terms of the Cycle Rate, Rc and Efficiency, E. From the study conducted, the study finds the best assembly system layout in terms of Cycle Rate, Rc and Efficiency, E to be the U-Shaped Assembly System.

Keywords: Assembly line configurations, Cycle Rate, Efficiency, Delmia Quest, Microsoft Excel, Straight-Line Assembly System, U-Shaped Assembly System.

1. INTRODUCTION

The term automated assembly directs towards the use of automated mechanical devices to carry out various assembly work and tasks in an automated assembly line. The traditional automated assembly line, which uses humans as workforce has drastically improved and progressed in recent years. Now, it is common in the world of production and assembly to see an assembly line that fully integrates automated machines and robots in the automated assembly line.

An automated assembly line design refers to the configurations in which the machines or the workstations are laid out. The system configurations of the machines are designed to achieve several demands such as production rate, lower cost, and higher productivity. Therefore, there is a need to include automated assembly line design in consideration since it brings significant changes in the performance output of the plant/factory. Moreover, a well-designed automated assembly line can also solve multiple line-related constraints such as work volume, ergonomic, cost and number of workers.

A U-Shaped Assembly System design is a configuration in which machines are arranged around a U-shaped line, while following the order in which operations are carried out. Machine operators work within the U-Shaped Assembly System which helps to keep machine operators closer to each other thus improve and teamwork.

In a Straight-Line Assembly System design, the machines are arranged next to each other in a long line or most commonly known as a serial line or flow line. Similar to a U-shaped line, the configurations of the machines follow the order in which operations are carried out. Figure 1-5 shows both layout configurations.

2. LITERATURE REVIEW

One advantage of the automated assembly system is that a minimal number of workers are usually required at the workstations [1] and [2] argues that an automated assembly system is constrained by then need for more product variants and thus incapable of providing product variability. A single model automated assembly line refers to the automated assembly line in which only one model is produced in the same line [3]. Single model automated assembly line is usually designed for products receiving high demand from customers or consumers as reported by [4]. Products that require mass production are more than often done in a single model automated assembly line. In a single model line, the same model is being produced, or assembled repeatedly in large quantities. There are several different automated assembly line configurations, such as U-Shaped Assembly System, Straight-Line, S-Line and more. All of these different configurations offers their own advantages and disadvantages [5]. The decision to plan an automated assembly line system is dependent on the product that is being produced.

In a U-shaped assembly line design, machines are configured around a U-shaped line, while following the order in which operations are carried out. Machine operators work within the U-Shaped Assembly System which helps to keep machine operators closer to each other thus improve communications [1] and teamwork [6]. In usual settings, a machine operator will supervise both the entrance and the exit of the line. The machine operators will also be able to work in two or more nonadjacent stations.

In a U-shaped assembly line design, machines are configured around a U-shaped line, while following the order in which operations are carried out. Machine operators work within the U-Shaped Assembly System which helps to keep machine operators closer to each other thus improve communications [1] and teamwork [6]. In usual settings, a machine operator will supervise both the entrance and the exit of the line. The machine operators will also be able to work in two or more nonadjacent stations.

The main constraint of a Straight-Line Assembly System design is that operators are spread out in a long line, and may be separated by walls of inventory [1]. This could cause issues such as communication between operators, quality control and also number of operators in a line. The U-shaped assembly line design has none of these disadvantages. However, there are also cases where the Straight-Line Assembly System design is more preferred to a U-shaped assembly line design. Cheng et al.,(2000) argues that a Straight-Line Assembly System is preferred when the transfer between machines are less complicated when there are no changes in direction. In addition, configuring a Straight-Line Assembly System design is also more economical and less cost dependent when compared to a U-shaped assembly line design [7].

Through simulation, organization can expect to the technology which helps them to develop and interact with all the processes in a plant from the beginning of the process and design before committing to the real production. One of the biggest benefits of using Delmia Quest is the user friendly and simple visual interface which allows user to accurately plan and analyse the preferred design of a manufacturing or an automated assembly line [8]. In this research, Delmia Quest is used as a simulation tool that helps in designing the assembly line systems and analyse the Efficiency, E of the system.

3. METHODOLOGY

In this study, two engineering software were used as the analysis tool. To achieve the objective, we integrate the use of software such as Delmia Quest and Microsoft Excel. Delmia Quest is a simulation software which allows user to develop and interact with all the processes in a plant from the beginning of the process and design before committing to the real production. In this study, Delmia Quest is used to design, and simulate the U-Shaped Assembly System and Straight-Line Assembly System.

The aim of Microsoft Excel in this study is for calculation and analysis purposes. There are three major tasks in this software which are data collection, calculation on data and analysis process. The following figure shows the flow in which this study will undertake to achieve the objectives.

4. RESULT AND DISCUSSION

A set of data a set data is gathered from findings in Delmia Quest and Microsoft Excel. The following are the results for each assembly system layout.

A. Straight-Line Assembly System

Figure 1 below shows the design of the Straight-Line Assembly System that has been created in Delmia Quest Software. From the figure, the study shows the total number of Machine is 5, Labour is set as 1, with both the Source and the Sink at the start and the end of the assembly system, respectively. All the elements are arranged horizontally in a straight line. After designing and setting up the parameters for the assembly system, the simulation is executed to run for 3600 seconds.

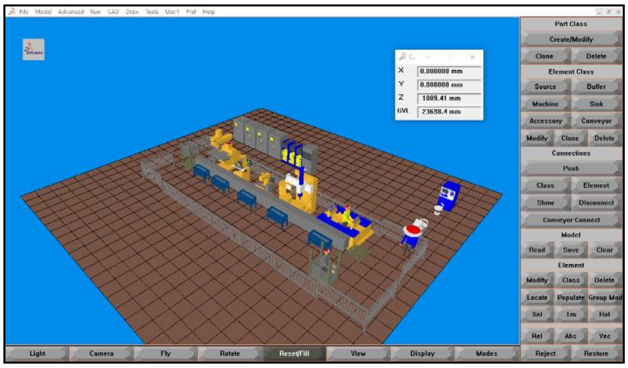

Figure 1: SLAS

After simulation is carried out for the Straight-Line Assembly System, a simulation run summary report can be produced from Delmia Quest. This report summarizes the entirety of the simulation by providing key information and findings regarding the simulation.

B. U-Shaped Assembly System

Figure 2 below shows the design of the Straight-Line Assembly System that has been created in Delmia Quest Software. From the figure, the study shows the total number of Machine is 5, Labour is set as 1, with both the Source and the Sink at the start and the end of the assembly system, respectively. All the elements are in a U-Shaped design where some machines are horizontal with each other while the others are arranged perpendicularly. After designing and setting up the parameters for the assembly system, the simulation is executed to run for 3600 seconds.

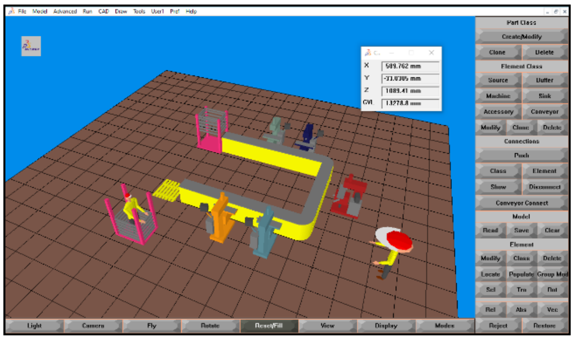

Figure 2: USAS

After simulation is carried out for the Straight-Line Assembly System, a simulation run summary report can be produced from Delmia Quest. This report summarizes the entirety of the simulation by providing key information and findings regarding the simulation.

C. Productivity

In Microsoft Excel, all the necessary information that had been collected from Delmia Quest's Summary Report is extracted and tabulated. The rationale behind this is to allow the information to be easily analyzed and compared side by side for both assembly systems.

After the tabulation of the information, a bar chart can be produced to further allow the comparison of both assembly systems to be fulfilled. From the chart, several observations and conclusion can be made.

For the total number of parts created, in 3600 seconds, both assembly system managed to create the same number of parts which is 360 parts/hour. However, when observing the total number of parts finished in 3600 seconds, a slight difference can be observed. For U-Shaped Assembly System, a total of 110 parts can be finished by the system within the given time. But for Straight-Line Assembly System, only 104 parts can be finished by the system. There is a difference of 6 finished parts between both systems. For the Machine Utilization a consistent pattern can be observed where the U-Shaped Assembly System achieve a slightly higher percentage of machine utilization compared to Straight-Line Assembly System. Lastly, for Conveyor Utilization the observation made is that Straight-Line Assembly System achieve a much higher percentage of Conveyor Utilization compared to Straight-Line Assembly System.

In addition, from the information gathered in Delmia Quest run Summary Report, a clear difference can be seen between both assembly systems. This disparity is most likely attributed to the layout of the assembly system as the layout being the most differentiated aspect between both assembly systems. This biggest main effect of the layout can be seen in the number of parts finished by both systems. Despite having created the same number of parts within the time given, the number of finished parts is not the same with the U-Shaped Assembly System finishing more parts than the Straight-Line Assembly System. The same can be observed for Machine Utilization with the U-Shaped Assembly System providing to be more utilized compared to Straight-Line Assembly System. The same cannot be said for the conveyor utilization where the Straight-Line Assembly System achieving a higher percentage of utilization compared to the U-Shaped Assembly System. This can be accredited to the conveyor layout of the Straight-Line Assembly System as being more direct and easy for the parts to travel compared to the U-Shaped Assembly System which has corners in the conveyor which may slow down parts movement in the conveyor.

The productivity of a system is denoted as the output divided by input. Figure 3 below shows the information regarding the output and the input for both assembly systems.

Analysis on Simulation Report		
Productivity		
Type of Assembly System	U-Shaped	Straight Line
No. of Parts Created *(Input)*	360	360
No of Parts Finished *(Output)*	110	104
Productivity *(%)*	*31%*	*29%*

Figure 3: Productivity from Delmia

The bar chart in figure 4 below shows the productivity for both assembly systems. From the chart, a 2% difference in productivity can be seen from both assembly systems, with the U-Shaped Assembly System proving to be more productive than the Straight-Line Assembly System.

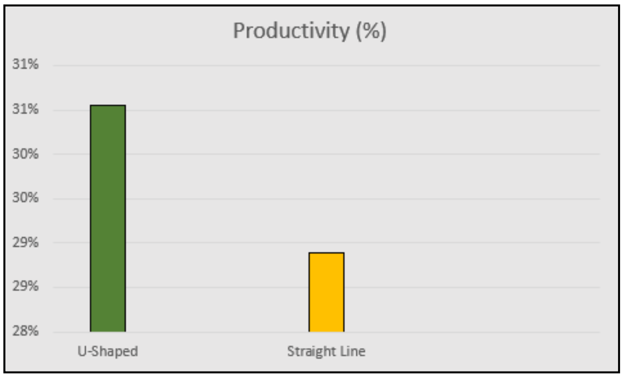

Figure 4: Productivity Chart

The difference in productivity is mainly contributed from the output generated from both the assembly systems.

D. Production Rate

In the previous subsection, a discussion has been made that sees the U-Shaped Assembly System finishing more parts compared to the Straight-Line Assembly System. This data concludes that the U-Shaped Assembly System is the more productive layout compared to the Straight-Line Assembly System. Production Rate is denoted as the amount of annual demand in units/year divided by the no of weeks plant operates per year multiplied by the number of shifts per week multiplied by hour per shift.

Analysis on Simulation Report		
Production Rate, *Rp*		
Type of Assembly System	U-Shaped	Straight Line
Annual Demand (units/year), *Da*	100,000	100,000
No of weeks plant operates per year	50	50
No. of Shift/Week, *Sw*	5	5
Hour/Shift, *Hsh*	7.5	7.5
Production Rate *(units/hour)*	*53.33333333*	*53.33333333*

Figure 5: Production Rate from Delmia

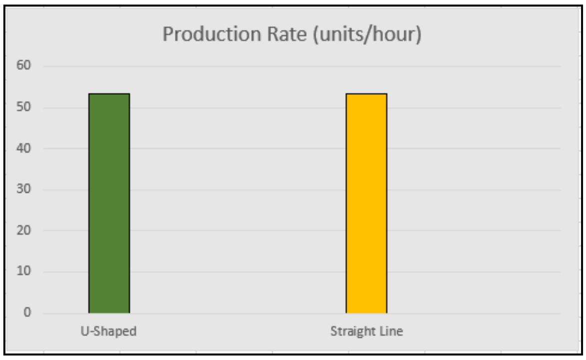

Figure 6: Production Rate Chart

For the production rate, both assembly system observes the same exact value, as production rate only serves as the guideline for the system to follow in an ideal condition.

Therefore, in an ideal condition, both assembly systems are required to produce about 54 units per hour to meet demand as can be seen on figure 5 and 6 respectively.

E. Cycle Time And Cycle Rate

Cycle time was calculated from the time taken for one part to complete the whole process from Source to the Sink. In an assembly system, the cycle time considers the machine service time, Ts, machine repositioning time, Tr and idle time of the system. From figure 7 and figure 8 below shows the data for both U-Shaped Assembly System, and Straight-Line Assembly System in terms of cycle rate.

Analysis on Simulation Report		
Cycle Time, *Tc*		
Type of Assembly System	U-Shaped	Straight Line
Cycle Time, *Tc (sec/parts)*	33	35

Figure 7: Cycle Time

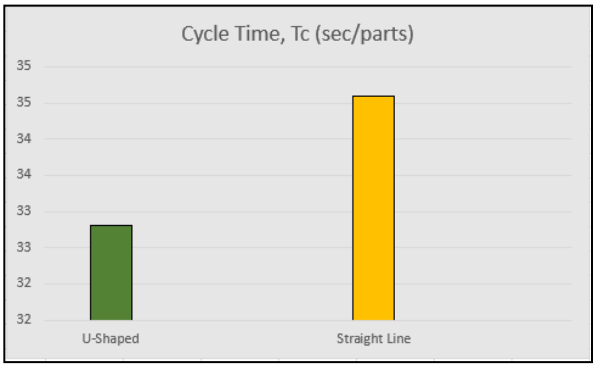

Figure 8: Cycle Time Chart

From the chart above, it is apparent that the Straight-Line Assembly System achieves a higher cycle time compared to the U-Shaped Assembly System. This means that the Straight-Line Assembly System would take a longer time for one part to finish the whole cycle compared to the U-Shaped Assembly System. Cycle Rate is denoted as an hour divided by the cycle time of the system. From the data tabulated in figure 9 and the chart created in figure 10, we can see that the USAS achieves a higher cycle rate compared to the SLAS.

Analysis on Simulation Report		
Cycle Rate, *Rc*		
Type of Assembly System	U-Shaped	Straight Line
Cycle Time, *Tc*	32.8 sec/parts	34.6 sec/parts
Cycle Rate *(cycle/min)*	*1.83*	*1.73*

Figure 9: Cycle Rate

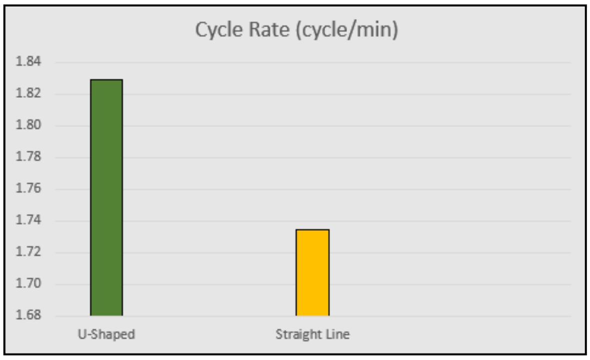

Figure 10: Cycle Rate Chart

A higher cycle rate means that the system can achieve a greater number of cycles within a limited amount of time. From the figure above, USAS achieves a higher cycle rate with 1.83 cycle/ min. This means that in one minute, USAS could complete 1.83 cycle compared to SLAS which could only complete 1.73 cycles in one minute. This allows the USAS to give out more output in the long run compared to SLAS.

F. Efficiency

In assembly system, efficiency concerns with the uptime and downtime of a system, regardless if it involves the machine, source, sink and even labor. Any changes that may cause a halt in the system is considered as the downtime. For our simulation, it is observed that both assembly systems manage to achieve a 100% efficiency as shown in figure below.

Analysis on Simulation Report		
Efficiency, *E*		
Type of Assembly System	U-Shaped	Straight Line
System Failure Time	0 Sec	0 Sec
Efficiency *(%)*	*100%*	*100%*

Figure 11: Efficiency

For efficiency, both assembly systems managed to achieve the highest value for efficiency which is 100%. This means that throughout the entirety of the simulation, none of the elements within the system encountered any downtimes. This may seem like a good thing to note, however it must be reminded that the report is obtained from a simulation, and as in any case of a simulation, more often that the simulation is carried out in the most ideal of conditions. So, despite both system showing a perfect value in efficiency, a real-time application may prove to be dissimilar and produce a varying result.

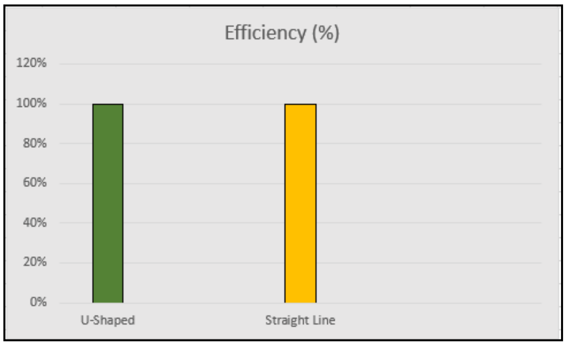

Figure 12: Efficiency Chart

In conclusion, the simulation created in Delmia Quest and the calculation and charting of data in Microsoft Excel helped the study to achieve the intended result. Table 1 below summarizes the result obtained from the analysis of both U-Shaped Assembly System and Straight-Line Assembly System. It explains that the USAS has managed to achieve the best result based on the parameters specified.

Table 1: Conclusion Best Assembly System		
Best Assembly System	Cycle Rate, R_c	Efficiency, *E*
U-Shaped Assembly System	1.83 cycle/min	100%

5. CONCLUSION

Based on the simulation and calculation made in both software in this study, the analysis for the best assembly line layout has been achieved successfully. The simulation showed the difference that both assembly system layout brings to the system, and the calculation further supports the result. The findings for both assembly systems show that different layouts do produce differing results and a comparison can be made.

From the discussion made in the previous chapter, the study finds that the U-Shaped Assembly System is the better layout in this assembly line layout comparison. This conclusion is made by observing several key elements behind the simulation done in Delmia Quest and supported by the calculation done in Microsoft Excel. In most of the comparison established, the U-Shaped Assembly System is consistently providing better results when compared to the Straight-Line Assembly System. From this, the study has been able to achieve the conclusion as shown in Table 2.

Table 2: Summary of The Results		
Parameters	Type of Assembly System	Value (Difference)
Number of Parts Created	Same Result	360 parts/hour (+0 parts)
Number of Parts Finished	U-Shaped Assembly System	110 parts/hour (+6 parts)
Machine Utilization	U-Shaped Assembly System	73% (+ 5%)
Conveyor Utilization	Straight-Line Assembly System	100% (+ 6%)

Productivity	U-Shaped Assembly System	31% (+2%)
Production Rate	Same Result	54% (+0%)
Cycle Time	U-Shaped Assembly System	32.8 sec/part (+1.8 sec/parts)
Cycle Rate	U-Shaped Assembly System	1.83 cycle/min (+0.10 cycle/min)
Efficiency	Same Result	100% (+0%)

REFERENCES

[1] CH Cheng, J Miltenburg and J Motwani. The effect of straight- and U-shaped lines on quality. *IEEE Trans. Eng. Manag.* 2000; **47**, 321-334.

[2] G Michalos, S Makris, N Papakostas, D Mourtzis and G Chryssolouris. Automotive assembly technologies review: challenges and outlook for a flexible and adaptive approach. *CIRP J. Manuf. Sci. Technol.* 2010; **2**, 81-91.

[3] P Sivasankaran and P Shahabudeen. Comparison of Single Model and Multi-Model Assembly Line Balancing Solutions. *Int. J. Comput. Intell. Res*. 2017; **13**, 1829-1850.

[4] M Groover. *Automation, Production Systems, and Computer-Integrated Manufacturing*. 1980.

[5] B Rekiek, A Dolgui, A Delchambre and A Bratcu. State of art of optimization methods for assembly line design. *Annu. Rev. Control*, 2002; **26**, 163-174.

[6] J Miltenburg. U-shaped production lines: A review of theory and practice. *Int. J. Prod. Econ*. 2001; **70**, 201-214.

[7] S Chand and T Zeng. A Comparison of U-Line and Straight-Line Performances under Stochastic Task Times. *Manuf. Serv. Oper. Manag*. 2001; **3**, 138-150.

[8] ZM Bzymek, M Nunez, M Li and S Powers. Simulation of a machining sequence using delmia/quest software. *Comput. Aided. Des. Appl*. 2008; **5**, 401–411.