Human-Machine Collaboration for Car Toys Assembly Line by Using Discrete Event Simulation Approach

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Abstract

The assembly process consists of sequences of complex tasks. Implementing automation to an assembly line is still quite challenging since human still plays a significant role in the assembly process. On the other hand, robots are able to achieve much higher performance than humans, especially when performing low-level cognitive tasks. Therefore, the robots' advantages can be combined with human abilities to improve the assembly process. Humans will frequently see robot integration in the assembly process in the future. This paper presents a human-machine collaboration (HMC) design for a car-toys assembly line and investigates the assembly line performances. Three scenarios are presented and analyzed in this work, e.g., the manual assembly line, integrating one collaborative robot, and integrating two collaborative robots. The performance analysis such as flow time, throughput, and utilization are done using Tecnomatix Plant Simulation. The scenario which has the best performance has been identified as a recommendation for future improvement of the existing system

Keywords
Assembly Line, Human-Machine Collaboration, System Design, Discrete Event Simulation

1. Introduction
Manufacturing systems need to be flexible as the rising trend of mass customization (Sandrin et al. 2018). Flexibility is one of the most important key elements for facing market changes and adaptability to customer demands. Car toy is one example of a product that has many varieties, and every month new models are coming out. The car toys assembly process does not require a complex process. However, since there is a lot of part varieties and part components that are small in terms of sizes, as shown in Figure 1, the car toy assembling process is still relying on human operators. Human on the other hands has its limitation such as endurance. In order to cope with human limitations, integrating machines and robots will be necessary.

Figure 1. Toy Car Components

It is worthy to note that integrating machines or robots into an assembly line is not an easy task. Since, a lot of factors such as factory layout, product specification, and other elements are needed to be noticed and considered. Human-machine collaboration (HMC) has been a growing issue for the past few years especially in Industry 4.0 era. The idea of HMC is to create a partnership between humans and machines, not create a machine as the servant of humans (Droder, et al., 2018) since humans and machines both have their advantages. The advantages such as human accuracy and machine endurance must be exploited and combined.

The purpose of HMC is to balance the collaboration of humans and machines. The output of human-machine collaboration is supposed to have the same result and quality or even giving better quality with more efficient production than manual work based on cost and time. The working environment from HMC also needs to be examined. These issues are critical since HMC is supposed to give more advantages to the system.

A cost-effective method is needed to observe how HMC able to give benefit to the assembly system and the estimated output can be measured. Thus, simulation modeling is the method that suitable for this research because of its capability to create scenarios, for experimenting, and to produce estimated output from a system that has not existed without creating a disturbance to the existing system (Bandini et al., 2009, Abar et al., 2017). In this study, a simulation model for car toys assembly line that will integrate collaborative robots is developed. The assembly line is a mock-up of the assembly process located at Swiss German University that refers to Toyota Laboratory at Rochester University as shown in Figure 2 (Sofianti et al., 2017, Kurniawan et al., 2019). In this research, there are several scenarios with different resources developed. System performances from each scenario will be investigated and the comparison between manual assembly line and assembly line that integrates collaborative robots into the system is analyzed.

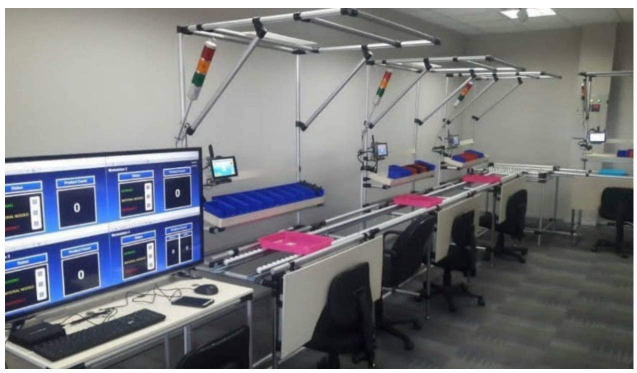

Figure 2. Car-Toys Assembly Line

2. Literature Review

2.1 Human-Machine Collaboration

Human-machine collaboration (HMC) is an important technology in the field of manufacturing. This is driven by the customer demand and product specification variation that require flexibility in a production line. Thus, the collaboration between humans and machines in a production system is often seen nowadays (Kurniawan et al, 2020). However, there are a lot of factors that need to be considered in order to make robot and human might collaborate in a manufacturing process. Elements such as factory layout, product bill of materials, available resources also need to be considered to make the manufacturing process might work well and increase efficiency (Amiri et al, 2019).

2.2 Simulation Modelling

Simulation modeling is a method of creating a virtual system that imitates and represents the behavior of the real-world system. Simulation modeling is used to develop and analyze a model in computer simulation software with various tools and features (Kikloski 2017, Kin et al. 2011). It is widely used to observe and solve problems in the system. Simulation modeling has many benefits, which are it is a cost-effective and fast method to study the system behavior, as well as able to evaluate a real-world system that is too complex to be modeled analytically with mathematical approach (Kin et al. 2011, Law 2013). System modeling is also used to predict the system behavior and performance when a major improvement or changes implemented into the system so that the risk of failure is reduced or even eliminated (Kikloski 2017). Several simulation modeling methods have different characteristics and purposes, which are discrete event simulation, system dynamics, continuous simulation, and agent-based simulation (Kin et al. 2011).

2.3 Discrete Event Simulation

Discrete event simulation or DES is a simulation method that simulates a real-world model which states changes only at a separate point (discrete) in time. The state changes happened because of an event which is an occurrence that may change the state of the system at a certain discrete point in time, and in between these events occurred, the system state remains the same (Kin et al. 2011, Law 2013). DES is more focused on process, event, and durations, as well as mostly done with aid of a computer since the numerical analysis is too complex to be solved manually (Banks et al. 2014). There are several DES software tools that can be utilized, including Tecnomatix, ARENA, and Anylogic. DES is widely used, especially for solving queuing processes, resource allocation, and solving bottleneck problems in the manufacturing process (Kampa et al. 2017, Banks et al. 2014).

Table 1. Previous study related to human-machine collaboration for assembly line by using simulation modeling approach

Reference	Method			Operation	
	DES	SD	ABS	Production	Assembly Line
Sudo & Matsuda, (2013)			v		v
Khedri Liraviasl et al., (2015)	v	v		v	v
Kurniawan et al., (2020)			v		v
Proposed Study (2021)	**v**				**v**

DES: Discrete Event Simulation, SD: System Dynamics, AB: Agent-Based

3. Methods

The research method used in this research is as shown in Figure 3.

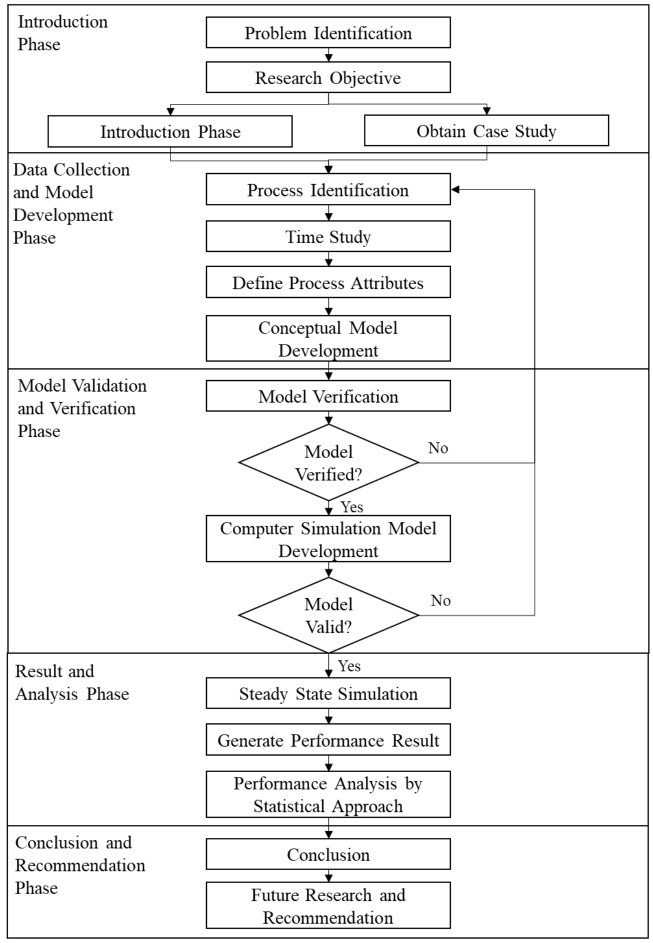

Figure 3. Research Framework

3.1 Introduction Phase

The research started with the introduction phase where the problem and research objective were identified, which are to evaluate and analyze the current system as well as the future improvements of the system and its performances. In this phase, the literature review is also done, as well as with obtaining study cases, which are the car toys manufacturing system with four workstations.

3.2 Data Collection and Model Development Phase

After the case study was determined, then the process continued to the data collection and model development phase, which identified the process in each workstation. Next, the time data of each process was collected through time study. The attributes of the system were also defined, and then the conceptual model is developed.

3.3 Model Validation and Verification Phase

The research activities proceed to the model validation and verification phase. The conceptual model developed was verified, and after it was verified, the model was developed in three scenarios including the existing system and proposed improvement, and later validated by using computer simulation.

3.4 Result and Analysis Phase

After validating the model, the research continued to steady-state simulation, then generated performance results of three scenarios in the system. The generated performance results were then evaluated and analyzed using a statistical approach.

3.5 Conclusion and Recommendation Phase

As the results of analysis, in the conclusion and recommendation phase, the scenario with the best performance was chosen as the recommendation for future improvement of the toy car manufacturing system.

4. Modelling and Simulation

4.1. Assembly Process and Time

The car toy assembly line, which is the study case of this research, has four workstations, Workstation 1 (WS 1), Workstation 2 (WS 2), Workstation 3 (WS 3), dan Workstation 4 (WS 4). The layout of the car toy assembly line is as shown in Figure 4. The assembly process starts from WS 1 where the main activity is attaching dynamo to the terminal and its plastic cover, and lastly, it is attached to the chassis. After finished, assembled part from WS 1 is transported to WS 2. The process continues to assemble and attach tires to the chassis in WS 2. The assembled sub-assembly is moved to WS 3. The roller is then assembled into the chassis by the screwing process in WS 3. Next, the sub-assembly transported to WS 4 and in WS 4, the body is attached to the chassis and the finished car toy is packaged.

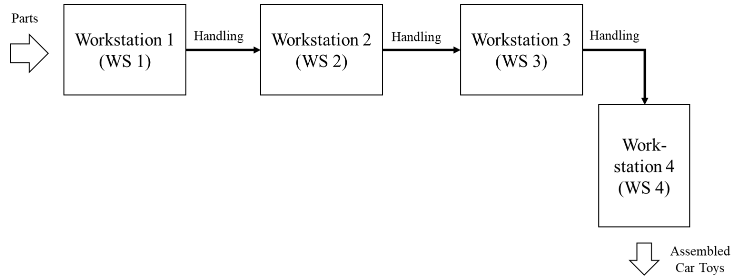

Figure 4. Layout of Car Toy Assembly Line

The processing time in each workstation is defined by using time study. The processing time data obtained by time study might vary. Therefore, the simulation's processing time input is following Normal Distribution. The processing time is as shown in Table 1.

Table 2. Assembly Activity, Time, and Resources Involved

Station	Activity	Time [μ,σ] (seconds)	Resources
Workstation 1 (WS 1)	Dynamo Attachment	187, 5	Operator
WS 1 to WS 2	Handling	10, 0.5	Operator
Workstation 2 (WS 2)	Tire Assembling	179, 2	Operator
WS 2 to WS 3	Handling	10, 0.5	Operator
Workstation 3 (WS 3)	Roller Screwing	228, 9.5	Operator
WS 3 to WS 4	Handling	10, 0.5	Operator
Workstation 4 (WS 4)	Body Assembling and Packaging	176, 3	Operator

As for the resources allocation, all process was done by four operators (human) in the current situation. For later simulation scenario development, the collaborative robots are introduced to the car toy assembly system for workstation 3 (WS 3) and handling. There will be some adjustment in the number of operators and processing time in WS 3 as well as handling from WS 2 to WS 3.

4.2. Simulation Development

The simulation of the car toy assembly model is developed in Tecnomatix Plant Simulation. The simulation is developed based on the current situation. In addition to the current model as the scenario 1, there are two other scenarios developed as the improvement of the system, so in total there are three simulation scenarios developed for the car toy assembly system. A collaborative robot is installed in workstation 3 or WS3 in scenario 2, which leads to processing time adjustment or reduction in WS3 from an average of 230 seconds to a constant time of 153 seconds. The other processing time remains the same and only three operators working in the system. For scenario 3, two collaborative robots are installed, one assigned in WS 3 and another installed in between WS 2 and WS 3 for material handling. Three operators are assigned and the processing time is the same as scenario 2, with the addition of handling time reduction from an average of 10 seconds to a constant time of 6 seconds. The scenario details can be seen in Table 2.

Table 3. Resources and Time for Simulation Scenarios

Scenario	Resource Involved			Time (s)	
	Operator	Screwing-Robot	Arm-Robot	WS 3 Processing Time	WS 2 to WS 3 Handling Time
Scenario 1	4	0	0	228	10
Scenario 2	3	1	0	153	10
Scenario 3	3	1	1	153	6

All the scenarios are developed based on the processing time data and the conceptual model. The simulation time is set for 8 hours or 28,800 seconds. The simulation environment developed for the models is as shown in Figure 3.

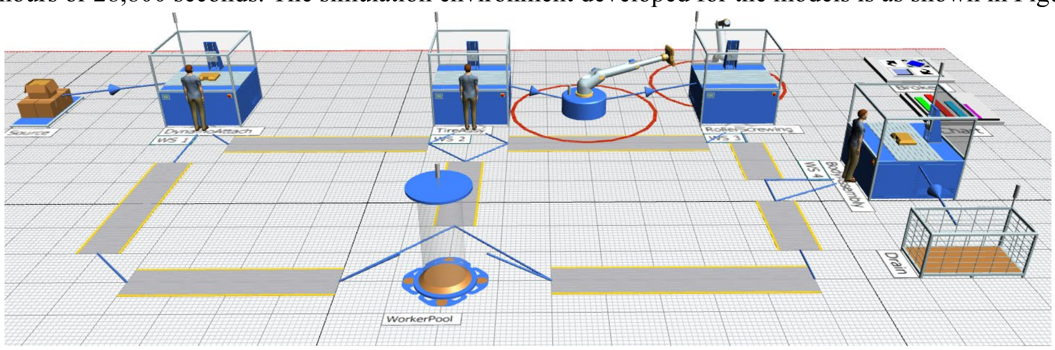

Figure 5. Simulation Environment (Scenario 3)

As shown in Figure 5, the simulation starts with the entity called source which generates the material input. A thin brown box represents the material or the mobile units (MU). The material initially goes to WS 1 and the operator started to attach some parts to the dynamo and attach the dynamo to the chassis. After the process in WS 1 is finished, the operator moves the sub-assembly part from WS1 to WS2. In WS 2, the tires are attached to the sub-assembly part and it is done by human operators in all scenarios. The next phase was material transport from WS 2 to WS 3, which is done by a human operator in Scenario 1 and Scenario 2, and by Collaborative Robot in Scenario 3. The roller is then attached to the sub-assembly with the screwing process in WS 3. The screwing process is executed by the human operator in Scenario 1 and by Robot in Scenario 2 and 3. The sub-assembly is then moved from WS 3 to WS 4 by human operators in all scenarios. In WS 4, the body is attached to the sub-assembly and the finished car toy is packaged. Lastly, the finished product or car toys are sent to an entity called drain representing the output.

5. Results and Discussion

Following the development of the simulation, the simulations are then run. The summary report and resources statistics, as the simulation results are generated after the simulation, is ended. The simulation results from three scenarios are shown in Table 3, Table 4, and Table 5. Table 3 shows the general summary of the simulation, while Table 4 shows the resources utilization results and Table 5 shows the utilization of the workstations from all simulation scenarios which run for 8 hours in Tecnomatix Simulation.

Table 4. System Performance - Simulation Result

Parameters	Scenario 1	Scenario 2	Scenario 3
Total Throughput (unit)	123	143	146
Throughput/ hour (unit/ hour)	15	18	18
Mean Life Time (seconds)	1169.7	915.4	904.7
Percentage of production (%)	88.72	98.69	99.01
Percentage of transport (%)	11.28	1.31	0.99
Percentage of Value Added (%)	65.91	75.94	76.84

Table 5. Resource Utilization - Simulation Results

Resource Utilization (%)	Scenario 1	Scenario 2	Scenario 3
Operator 1	83.4	88.46	90.72
Operator 2	83.75	92.12	94.44
Operator 3	83.21	91.48	93.84
Operator 4	82.37	0	0
Screwing Robot	0	76.5	78.39
Arm Robot	0	0	2.06

Table 6. Workstation Utilization - Simulation Result

Workstation Utilization (%)	Scenario 1	Scenario 2	Scenario 3
WS 1	82.21	94.94	97.36
WS 2	77.83	89.94	92.19
WS 3	98.67	76.5	78.39
WS 4	74.92	87.19	89.45

Comparison between simulation scenarios can be performed to see the parameter value and the gap between each scenario and determine which scenario has better performances. From the simulation results, when system performance is discussed, scenario 3 is giving the highest output, shortest flow time, and the smallest percentage of transportation time of parts based on 8 hours of simulation time (Table 3). Comparison result leads to an insight into how the arm-robot assigned for material handling, in this case, can reduce transportation time and enhance the overall performance of the system.

The most significant impact of the three scenarios is when scenarios 1 and 2 are compared. Installation of the collaborative robot into WS3 boosts the system throughput by 20% per hour and decreases flow time by 21%. This might happen because the installed robot has less processing time and process time can be done constantly. One advantage of having a collaborative robot is its endurance and ability to produce constant processing time rather than human. However, it does not mean a human is less effective because not all types of robots can be installed into the assembly line. First, the task that required a lot of complexity and detailed movement still rely on humans. Second, the task given to collaborative robots is supposed to be much simpler and more repetitive because collaborative robots still having a lot of limitations in movement trajectory.

6. Conclusion

Human-machine collaboration still quite a challenge in the assembly line since it required a lot of complexity to complete a finished product. This paper presents scenarios of collaborative robot implementation into an assembly line. The collaborative robot might impact overall system performances positively and can be an alternative way to enhance productivity. However, not all types of tasks can be executed by the collaborative robot, and assembly lines still partially rely on human operators. Thus, the task assignment and job distribution between humans and machines would be a critical factor in a human-machine collaboration assembly line. Based on the findings, the installed collaborative robot into WS3 gives significant impact to the system by boosting the system throughput by 20% per hour and reduces flow time by 21%. A further study for determining task allocation between human and machine for car-toys assembly process and workstation that can be changed by machine is required since this study only uses an arm-robot for material handling and a screwing-machine for a particular workstation to find a better overall system output.

References

Abar, S., Theodoropoulos, G. K., Lemarinier, P., & O'Hare, G. M. P., Agent-Based Modelling and Simulation tools: A review of the state-of-art software, *Computer Science Review*, 24, pp. 13–33, 2017

Amiri, F., Shirazi B., and Tajdin A., Multi-objective simulation optimization for uncertain resource assignment and job sequence in automated flexible job shop, *Appl. Soft Comput. J.*, vol. 75, pp. 190–202, 2019.

Bandini, S., Manzoni, S., & Vizzari, G., Agent-based modeling and simulation: An informatics perspective. Jasss, 12(4), 2009

Banks, J., Carson II, J.S., Nelson, B. L., Nicol, D. M., *Discrete-Event System Simulation*, 5th Edition, Pearson Education, 2014.

Droder, K., Bobka, P., Germann, T., Gabriel, F., and Dietrich, F., A Machine Learning-Enhanced Digital Twin Approach for Human-Robot Collaboration, *7th CIRP Conference on Assembly Technologies and Systems*, pp. 187-192, 2018.

Kampa, A., Golda, G., and Paprocka, I., Discrete Event Simulation Method as a Tool for Improvement of Manufacturing Systems, *Computers*, Vol. 6, no. 1, 2017.

Khedri Liraviasl, K., El Maraghy, H., Hanafy, M., & Samy, S. N., A framework for modelling reconfigurable manufacturing systems using hybridized Discrete-Event and Agent-based simulation. *IFAC-PapersOnLine*, *28*(3), 1490–1495., 2015

Kikloski, M., Study of Production Scenarios with the Use of Simulation Models, *7th International Conference on Engineering, Project, and Production Management*, pp. 321-238, 2017.

Kin, W., and Chan, V., Foundations of System Modeling, *Wiley Encyclopedia of Operations Research and Management Science*, John Wiley & Sons, Inc., 2010

Kurniawan, I., Awibowo, S., and Pratama, A. T., IoT Integrated Assembly Line - a conceptual model development for car toys assembly line, *1st International Conference on Engineering and Management in Industrial System (ICOEMIS 2019)*, vol. 173, 2019.

Kurniawan, I., Caneca, V. I., Power, J. M., & Sofianti, T. D., System Modelling and Simulation for Study of Human-Machine Collaboration Technologies Implementation on Assembly Line, *ICONETSI: Proceedings of the International Conference on Engineering and Information Technology for Sustainable Industry* (pp. 1 - 5). Tangerang: Association of Computing Machinery, 2020 doi:https://doi.org/10.1145/3429789.3429799

Law, A. M., *Simulation Modeling and Analysis*, 5th Edition, McGraw-Hill Education, 2013.

"Rochester Institute of Technology," [Online]. Available: https://www.rit.edu/facilities/toyota-production-systems-lab.

Sandrin, E., Trentin, A., & Forza, C., Leveraging high-involvement practices to develop mass customization capability: A contingent configurational perspective, *International Journal of Production Economics*, 196, 335-345, 2018

Sofianti, T. D., Awibowo, S., Zen, T., Saraswati, T., Ferdiansyah, A. R., Mustafa, R., and Kurniawan, I., Design of Computer Integrated Assembly Line, *ICCMA 2018: Proceedings of the 6th International Conference on Control, Mechatronics and Automation October 2018*., pp. 144–148, 2018.

Sudo, Y., & Matsuda, M., Agent based manufacturing simulation for efficient assembly operations. *Procedia CIRP*, *7*, 437–442. 2013.

Biography

Jessica Florencia is a teaching and laboratory assistant in the Department of Industrial Engineering at Swiss German University, Indonesia. She earned Bachelor of Engineering (double-degree) from Swiss German University, Indonesia, and Fachhochschule Südwestfalen, Germany. Currently, she is pursuing her master's degree at Department of Industrial Engineering, University of Indonesia. She has published a paper with a topic related to knowledge management and recently supports research about simulation and production systems.

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