Automated Material Handling System and Inspection System Model for Flexible Manufacturing Systems Learning

Ari Setiawan, Hans Pratama, Kelvin Setyadi, Eka Kurnia Asih, Vina Sari Yosephine
Dept. of Industrial Engineering
Institut Teknologi Harapan Bangsa, Bandung, Indonesia
ari_setiawan@ithb.ac.id, vinayosephine@ithb.ac.id

Abstract

Manufacturing system research and education have been struggling to catch up with the digital transformation movement. The manufacturing system becomes very complex with the incorporation of IoT, artificial intelligence, additive manufacturing, and data analytics. This gap is due to the outdated manufacturing curriculum and the limited experimental model in laboratories. The Institut Teknologi Harapan Bangsa has been progressively building a flexible manufacturing system model that consists of CNC machines, automated material handlings systems, and connected manufacturing execution systems to accommodate research and education. This particular study discusses the design of a stacker crane model controlled by an embedded single board and a quality control system with artificial intelligence. Our experimental investigation shows that the model enables students and faculties to perform more research and studies on a complex manufacturing system.

Keywords

Flexible Manufacturing System, Model, Stacker Crane, Inspection System, Education

1. Introduction

This research is intended to model a Flexible Manufacturing System (FMS) for higher education purposes. Unlike the traditional job shop or flow shop system, the FMS is a modern manufacturing system intended to fulfill the middle volume of production with a mid-volume of product variants. We focus on the development of the automated material handling system and the production station. The material handling system in FMS consists of the transport system and storage system. The main production system consists of automatic machining tools that are commonly called the machining center. The FMS is controlled by the integrated computer system that manages the material handling system, storage, and production system. This computerized system schedules, monitors, and controls production activities (Stecke, 1992).

In this digital transformation era, such FMS comprehension needs to be developed and taught in universities for students learning. However, the attempt is usually limited to the computer model, for instance, Nylund et al. (2019) develop a virtual FMS model for teaching advanced manufacturing. To answer the education gap, we develop a laboratory-sized FMS system focusing on the production planning and control and industrial automation. Some early studies related to data science, machine learning, and IoT technology have been conducted to support this research. Those studies include Object-Oriented Modeling to support FMS scheduling with the consideration of tools age (Setiawan et al, 2019). Also, Setiawan et al. (2018) designed a tools condition monitoring system using vibration sensor, temperature sensor, and power-consumption monitoring. Setiawan et al. (2020) has also designed a network sensor in an FMS system. These studies focused on an isolated system in FMS. The model to be developed in this model is intended for a higher education purpose; it consists of the manufacturing execution systems, material handling systems, and computer control systems

1.1 Objectives

In this paper, we intend to develop a material handling system that can pick and deliver material from the storage, loading-unloading station, and manufacturing execution systems. The material handling system concept is based on the stacker crane concept. Also, we develop an inspection system function to model the quality control in our FMS model. We chose the machine learning-based quality control to build a visual inspection system.

2. Literature Review

Little research has developed the FMS model for education. Nylund et al. (2019) developed the virtual FMS model for education systems in Finland. This FMS model is realized in the visual simulation consists of the stacker-crane model, loading-unloading station, material pallets, machining pallets, and machining centers. All operation and material movement is visualized on the computer screen imitating the FMS behavior. The model in this study is influenced by the Physical System FMS Training Centre by Toivonen et al. (2018). The model is a simulator that functions according to the actual FMS operation. Also, Kluz and Antoz (2019) developed an FMS simulation for education that focuses on the operation performance in regard to its average number of products waiting in a queue, the average time of a product waiting in a queue, and a manufacturing system as well as the expected downtime of a cell. Kluz also proposed a FMS simulation as a part of analysis of theoretical basics to explain the mass service systems. The objective of the simulation is to determine the configuration of the flexible manufacturing cell. David and Lanz (2018) also develop the digital twin model to support the FMS study.

The previous papers are the computer simulation approach to bring the FMS into education. Sometimes the simulation in the computer takes many assumptions that there are no errors while the simulation is running. For-example, the dimension error in the products is sometimes neglected. Marsico (20020) in 2002 prepared an FMS course in Penn State, incorporating a CNC lathe, a conveyor belt, gravity feeder, and a six-axis robot. Rajamony and Hilmi (2007) proposed a six-axis robot and a CNC lathe as the component of the FMS teaching in university laboratories. Those FMS equipment are the real industrial equipment that usually requires high investment and maintenance costs. In recent years many universities are planning to develop low investment cost FMS model that still shows the FMS function. Mourtzis et al. (2020) proposed a design and development of a flexible manufacturing cell in the learning factory paradigm. They proposed a system that requires the participation of students to design a product by CAD and then sent the file to the 3D printer. The 3D printer is now a sophisticated machine that can produce many products instead of machining products. The part dimension, made by a 3D printer, is going to be checked by a high-definition camera. The next process is the milling process by the CNC milling. The transportation of the parts is done by a robotic arm. While Bartelt et al. (2020) developed the production system for training to produce customizable wooden products by a laser cutting machine. The handling robots are utilized to load and unload the cutter and place the product on the conveyor. Sahu et al. (2020) proposed the improvement in manufacturing by adding augmented reality (AR). The concept of artificial intelligence (AI) in AR was proposed to assist the manufacturing application. No report has been found regarding the implementation of AR in the FMS learning. Meanwhile, Department of Industrial and Systems Engineering at KAIST created the LEGO System for education in manufacturing system (Jang and Yosephine 2016). Students build a manufacturing system as well as an FMS consisting of processing machine model, transportation system model and automated warehouse stocking (AS/RS) system. The systems might be to demonstrate the concept of the smart factories which equipped with Internet of Things (IoT).

Our FMS model in this paper is a miniature laboratory size for student learning. It is controlled by the single-board computer (SBC), sensors, and actuators. The model consists of three main modules: the production module, the material handling module, and the production planning and control module. The production module consists of two-axis CNC machines that engraves a wooden plate. The material handling system consists of a stacker crane that transport the material and pallet from and to the storage system. The production planning and control is designed to mimic a mini Enterprise Resource Planning (ERP) integrated into the quality control system. The size of the model is 1500mm x 500mm and the grand design of the FMS model is shown in Figure 1.

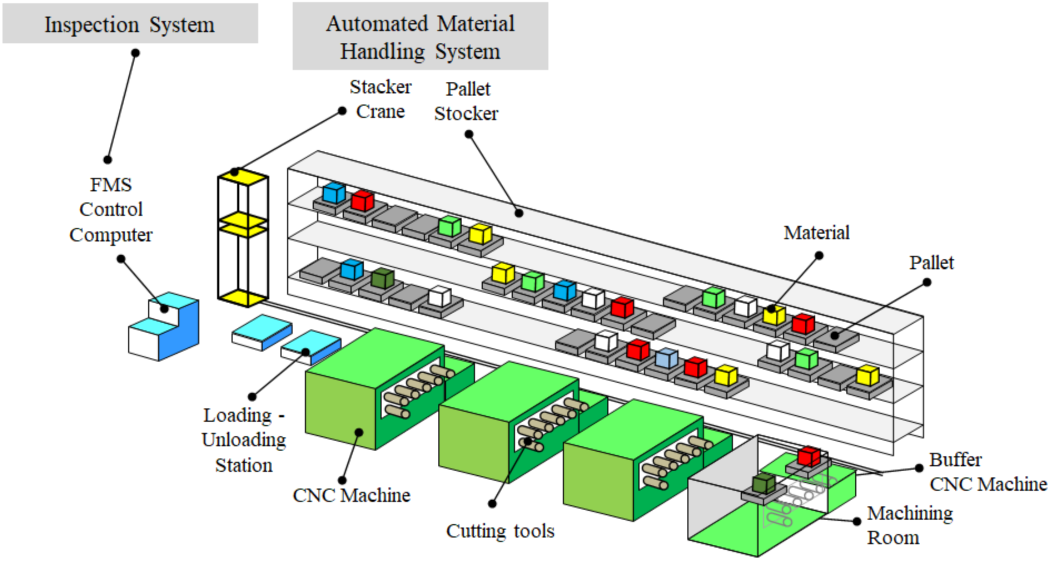

Figure 1. The grand design of the miniature FMS model

3. FMS Model Construction

In this section, we will report the established FMS components: the stacker crane and the inspection systems. In our previous study (Setiawan and Sekali, 2021), the stacker crane has been developed and reported with a low accuracy of 1.33 mm. In this study, we presented the improvement of the design.

3.1 Automated Material Handling System Model

The automated material handling system or the stacker crane has several main components. The first one is the bottom frame that moves in a longitudinal movement of the X-axis. The mast component moves in Y-axis vertical direction. The carriage is the component that retrieves and storage the products using from the pallet stocker, loading-unloading stations, and the CNC machines. This configuration is shown in Figure 2.

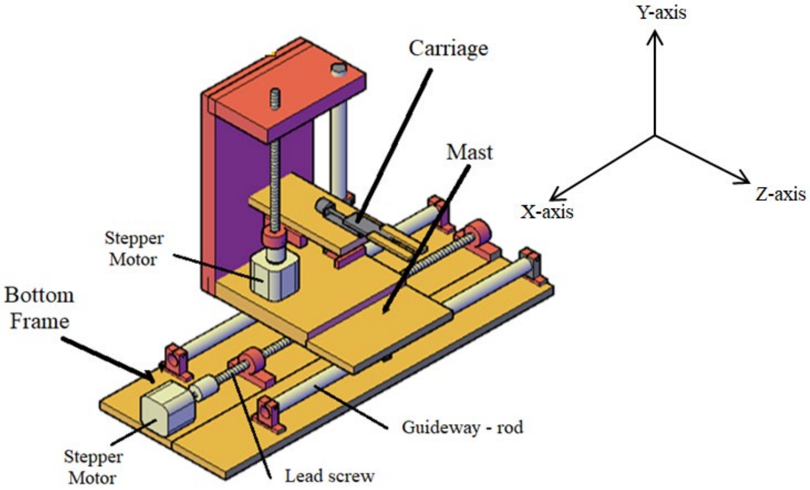

Figure 2. The construction of stacker crane model in the material handling system.

The stacker crane in this model has higher accuracy compared to its previous result, which is 0.43 mm. The modification includes the use of rigid materials such as acrylic for the base bottom. In our preliminary study, the base material is built from wood (David and Lanz, 2018). The consequence of the acrylic is the heavier load for the crane that droves the mast in a periodic moves along with the bottom frame. The mast was supported by one guideway, however in this model, two parallel guideway rails are added. The mast component is designed in C-shape to ensure the carriage can move well vertically. The body of the mast is built by acrylic with a metal fork.

The actuator of the stacker crane is composed of the stepper motor Nema. Two stepper motors of torque 3.2 kg-cm are installed to the bottom frame to drive the mast component in the horizontal direction or X-axis. The same motor is also installed on the mast for the vertical carriage movement or the Y-axis. A stepper motor with the mechanism of a computer disk is installed for the carriage to lift the pallet. We use the motor driver L298N and the single board computer, Arduino Uno, to control this motor mechanism. The movement is controlled by the module HC-05 that is assembled on the single-board computer. Figure 3 shows the mechanism of the stacker crane model mechanism.

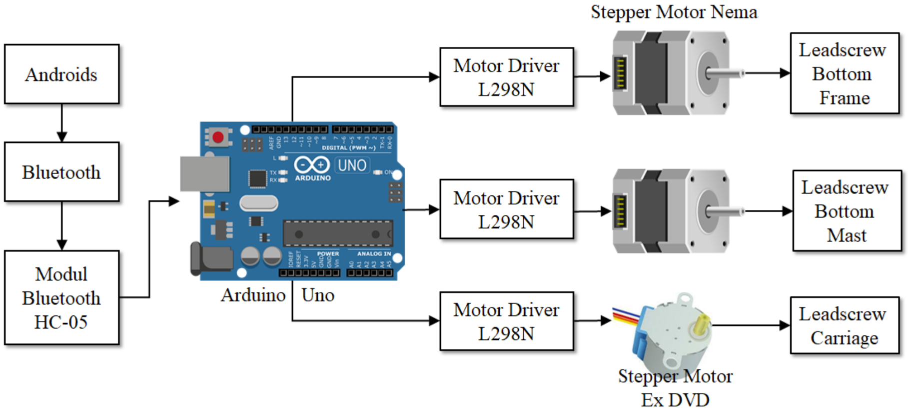

Figure 3. Diagram of model stacker crane control.

3.2 Inspection System Model

The FMS model is also equipped with an automatic quality control system. The product goes under inspection to endure the standard of the product. This initial study focuses on the computer vision methodology to inspect the shape of the product. In this FMS, the inspection system can classify two objects: sphere (white/yellow) and block. The image is capture using a 1080p web camera to ensure the HD quality of an image. The dataset is trained with three backgrounds: black, white, and green. The system application is developed with MATLAB imaging support package, machine learning, and computer vision support. The application consists of training, collect images, and classification. The data set consists of 640×480 pixels is trained with the AlexNet architecture. The transfer learning is then applied to the FMS model to classify the product. This classification process determines whether the object of the test is the sphere of the block. Figure 4 explains the inspection system of the FMS model.

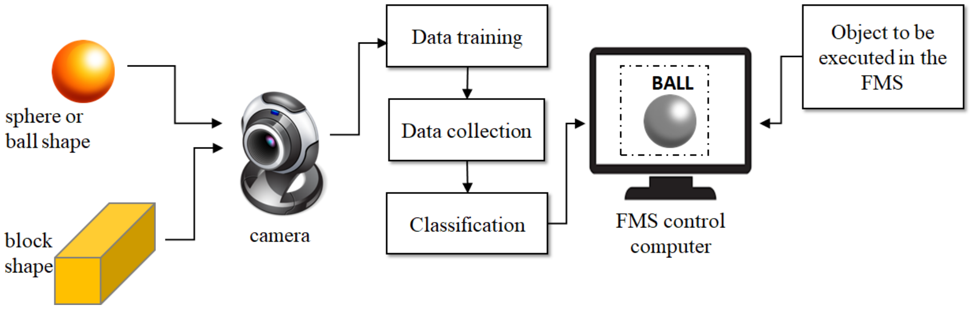

Figure 4. Model inspection system process in FMS

4. Testing and Data Collection

The Stacker Crane Testing

The stacker crane and inspection system have been verified with several experiment scenarios. The purpose of the testing for the stacker crane is to check the repeatability and accuracy of each crane's component.
The first test is the accuracy of the bottom frame horizontal movement. The test procedure is executed by instructing the bottom frame to move from a position to five other positions at a certain distance. The coordinates of the five positions are entered through the Androids application on mobile devices. The coordinates of each bottom frame position are as follows

Table 1. The coordinate of the bottom frame test position in x-axis.

Position	Coordinate in X axis in mm
B-1	x = 0
B-2	x = 66
B-3	x = 132
B-4	x = 199
B-5	x = 265

Based on seven testing scenarios, each of 20 tests can be collected the maximum error of overshoot or undershoot from the bottom frame when it stops at the destination position. Overshoot is a condition where the bottom frame stops at a location that is too far away, while undershoot is a condition where the bottom frame stops before the intended location. Measurements were carried out using a linear scale with a distance between scales of 1 mm. The testing shows that the repeatability and the accuracy have a maximum error of 1 ± 0.5 mm.

Table 2. The result of the bottom frame testing.

Number of testing sets	Start position	Destination position	Maximum Overshoot or undershoot in mm
1	B-1	B-2	0
2		B-3	-1
3		B-4	+1
4		B-5	0
5	B-2	B-1	0
6		B-3	-1
7		B-4	+1
8		B-5	0
9	B-3	B-1	0
10		B-2	0
11		B-4	+1
12		B-5	0
13	B-4	B-1	0
14		B-2	0
15		B-3	-1
16		B-5	0
17	B-5	B-1	0
18		B-2	0
19		B-3	-1
20		B-4	+1

Second, we tested the vertical carriage movement in the Y-axis. The second test is carried out by testing the vertical movement of the carriage on the y-axis which consists of three levels or three positions. The y-axis component has been equipped with a linear scale with an accuracy between scales of 1 mm. Each y-axis position is explained in table 3. With a test scenario similar to the bottom frame test, seven sets of tests have been carried out. The experiment shows that the maximum error is 1 ± 0.5 mm as explained in table 4.

Table 3. The coordinate of carriage positions in y-axis

Position	Coordinate in Y axis (in) mm
C-1	y = 84
C-2	y = 105
C-3	y = 124

Table 4. The result of the carriage testing

Number of testing sets	Start position	Destination position	Maximum overshoot or undershoot in mm
1	C-1	C-2	0
2		C-3	0
3	C-2	C-1	0
4		C-3	-1
5	C-3	C-1	0
6		C-2	-1

Third, we tested the Z-axis movement of the carriage. The experiment shows that the carriage can move 28cm long with the exact result. Last, is the experiment to move the crane from one station to another station. The purpose of this experiment is to check the accuracy of the crane to move between stations. This is necessary to check the ability of the material handling system to handle the material. All this mechanism is controlled by an android smartphone application. From 84 experiments, five products were not delivered correctly. We conclude that the material handling system has 94% success.

The Inspection Model Testing

The inspection system verification is performed using spheres shape object with white and orange colors with multiple backgrounds: green, black, and white. The test is performed in multiple levels of lighting: bright and dimmed. Also, the distance between the camera and the object is 22cm and 26 cm. The same setting is also performed on the block shape object. All scenarios are executed five times with 30 trials in each experiment. In total, the test is performed toward 7200 pictures. The success rate is defined as the ability of the FMS system as a whole in classifying the object. The testing shows that the testing of sphere reaches 3553 correct and 47 test wrong, while the result for the block has a lower success rate than the sphere object. The figure 5 shows the photo of the testing condition for inspection model system in laboratory. The result of the inspection model testing for block shape and sphere shape objects are shown in table 5 and table 6.

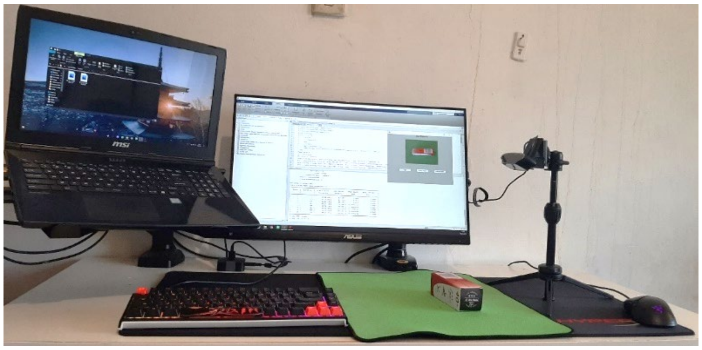

Figure 5. The testing concept for inspection model system in laboratory

Table 5. The result of the inspection model testing for block shape object.

Object	Back-ground	Height in mm	Lighting	Total correct decision	Total Error	Accuracy
Block	Black	220	Bright	292	8	97,33%
			Dimmed	300	0	100%
		260	Bright	266	34	88,67%
			Dimmed	183	117	61%
	Green	220	Bright	200	100	66,67%
			Dimmed	178	122	59,33%
		260	Bright	41	259	13,67%
			Dimmed	80	220	26,67%
	White	220	Bright	0	300	0%
			Dimmed	1	299	0,33%
		260	Bright	0	300	0%
			Dimmed	17	283	5,67%

Table 6. The result of the inspection model testing for sphere shape object

Object	Back-ground	Height in mm	Lighting	Total correct decision	Total Error	accuracy
Sphere	Black	220	Bright	287	13	95,67%
			Dimmed	290	10	96,67%
		260	Bright	300	0	100%
			Dimmed	300	0	100%
	Green	220	Bright	290	10	96,67%
			Dimmed	300	0	100%
		260	Bright	300	0	100%
			Dimmed	300	0	100%
	White	220	Bright	300	0	100%
			Dimmed	300	0	100%
		260	Bright	300	0	100%
			Dimmed	286	14	95,33%

5. Discussion

Based on the testing, the accuracy of the mast movements is affected by the friction of the guideways and leadscrew. This can be solved by adding grease or lubricant to the movement parts. On the other hand, the vertical movement of the carriage is disturbed by the increase in temperature. This is caused by a poor electrical connection and solved by replace to better electrical connection. The testing of the stacker crane model returns a five times failure due to the weak pallet grip. This is also due to the vibration on the stacker crane that causes the pallet to fall. The material handling system in the FMS model has a 94% of success.

In regards to the inspection system testing, we can conclude that the background aspect, lighting, and distance influence directly the system's accuracy in classifying the shape of the object. The data set quality also influences the accuracy of the system. The addition of data set can improve the accuracy of the system. In the FMS model, it is essential to ensure that the background, lighting, and distance are isolated with consistent scenarios.

The development and experiments of the FMS models have been taking place since 2017 involving several fourth-year undergraduate students working on their final projects in the Industrial Engineering Department. The student's response to the assignment shows promising learning results. The forum group discussion conducted with the students indicates that students have a clear understanding of a flexible manufacturing systems concept. They understood that each component in the system must be integrated in order to achieve a high manufacturing performance, as each component influences other parts of the system. The students also gain a sufficient understanding of the industry digitalization in regards to the industry 4.0 concept. Moreover, the students show a great interest in the application of artificial intelligence in the manufacturing systems. This indicates that such active learning triggers students on continuous learning, which is the exact skills that are required in the digital transformation era. Finally, we can conclude that these projects show that the students were able to understand modern manufacturing not only from a single process perspective but also from a systemic view.

6. Conclusion

We have built an FMS model with the stacker crane miniature that functions as the actual crane. The crane has higher accuracy than the previous model. The testing shows that there is still room for improvement for the fork to increase the repeatability and accuracy. We also showed that it is possible to model the inspection system in the FMS model to incorporate the quality control systems with computer vision. These models are intended to supports students learning on the flexible manufacturing system.

References

K.E.Stecke, Planning and Scheduling Approaches to Operate a Particular FMS, *European Journal of Operational Research*, Vol. 61, Page: 273-291. Elsevier Science Publisher Souier, 1992

Nylund, H., Valjus. V., Toivonen, V., Lanz, M., Nieminen, H., The Virtual FMS – An Engineering Education Environment, *Procedia Manufacturing* 31 pp.251-257, 2019.

Setiawan, A., Wangsaputra, R., Martawirya, Y.Y., and Halim, A.H., An Object-Oriented Modeling Approach for Production Scheduling on CNC-Machines in Flexible Manufacturing System to Maximize Cutting Tool Utilization, *Journal of Advanced Manufacturing Systems*, Vol.18, No.2, 293-201, 2019.

Setiawan, A., Angela, D. and Irawan, B. Modelling of Cutting Tool Condition Monitoring System (CTCMS) to Support Industry 4.0, *MATEC Web of Conference* , 204, 02012, pp.1-10, 2018

Setiawan, A., Silitonga, R.Y.H., Angela, D. and Sitepu, H.I, The Sensor Network for Multi-agent System Approach in Smart Factory of Industry 4.0, *International Journal Of Automotive And Mechanical Engineering* (IJAME), Vol.11., Issue 4, 8255 – 8264, 2020.

Toivonen, V., Lanz, Minna, Nylund., Hasse and Nieminen, H., The FMS Training Centre – A Versatile Learning Environment for Engineering Education, *Procedia Manufacturing* 23, pp.135-140, 2018.

Kluz, R, Antoz, K, Simulation of Flexible Manufacturing Systems as an Element of Education Towards Industry 4.0, *Advances in Manufacturing II*, Volume 1, pp.332-341, 2019.

David, J. Lobov, A. and Lanz, M. Leveraging Digital Twins for Assisted Learning of Flexible Manufacturing Systems, *IEEE*, pp. 529- 535, 2018.

Marsico, S.A., Incorporating a Flexible Manufacturing System into a Design Course, Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition. P 7.648.6, 2002

Rajamony, B., Hilmi, A.,H., Teaching Flexible Manufacturing System in University Education for Future Engineers, *Schools of Manufacturing Engineering, University Malaysia Perlis*, 2007

Mourtzis, D., Angelopoulos, J., and Dimitrakopoulos, G., Design, and development of a flexible manufacturing cell in the concept of learning factory paradigm for the education of generation 4.0 engineers, 10th *Conference on Learning Factories*, CLF 2020, *Procedia Manufacturing* 24, pp.361-366, 2020

Bartelt, M., Stecken, J., and Kuhlenkoetter, B., Automated production of individual products for teaching I4.0 concept., 10th *Conference on Learning Factories*, CLF 2020, *Procedia Manufacturing* 24, pp.337-342, 2020

Sahu, C.J., Young, C., and Rai, R., Artificial intelligence (AI) in augmented reality (AR)-assisted manufacturing applications: a review. *International Journal of Production Research*, Vol.59, No.16, pp.4903-4949, 2020

Jang, Y.J., and Yosephine, V.S., LEGO robotics based project for industrial engineering education, *International Journal of Engineering Education*, Vol.32 No.3, pp1268-1278, 2016

Setiawan, A. and Karo Sekali, N. Perancangan Model Stacker Crane Flexible Manufacturing System untuk Pembelajaran di Institusi Pendidikan, *Jurnal Rekayasa Sistem Industri*, Vol.10, No.1, pp.44-54, 2021

Biographies

Ari Setiawan. Ari Setiawan is a lecturer at Industrial Engineering Department, as well as the lecturer at Supply Chain Department Institut Teknologi Harapan Bangsa, Bandung, Indonesia. He received his bachelor degree on Mechanical

Engineering, Institut Teknologi Bandung (ITB) and received the Master degree from the Industrial Engineering and Management, ITB. He received the doctoral degree from Industrial Engineering and Management, ITB. His research interests are in FMS, Automatic Production Scheduling and Production Controlling, Maintenance, Machine Tools and Manufacturing Processes.

Hans Pratama. Hans is an undergraduate student of the Department of Industrial Engineering at Institut Teknologi Harapan Bangsa. His research interest is in automotive, sensors, and the embedded systems.

Kelvin Setyadi. Kelvin is an undergraduate student of the Department of Industrial Engineering at Institut Teknologi Harapan Bangsa. He has interest in artificial intelligence and computer vision research.

Eka Kurnia Asih. Eka is a lecturer of the department of Industrial Engineering at Institut Teknologi Harapan Bangsa. She graduated her bachelor degree and master degree form Industrial Engineering Dept. Institut Teknologi Bandung. Now she is continuing her doctoral program in the Industrial Engineering Dept. Institut Teknologi Bandung.

Vina Sari Yosephine. Vina is a member of the department of Industrial Engineering at Institut Teknologi Harapan Bangsa. She completed her bachelor from Institut Teknologi Bandung in Indonesia and PhD Degree from Korea Advanced Institute of Science and Technology.