An Implementation of Internet of Things for Digitalization of Kanban Production System

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Abstract— *Just-In-Time production system in the form of kanban has been implemented in many production processes to optimize the production output. Internet of Things (IoT) has been integrated into production systems in digitalizing production processes as well as obtaining and gathering real-time information on the factory floor through sensors, actuators, and networks. In this study, an application of IoT into kanban and production systems was proposed. The proposed electronic kanban system is composed of Radio Frequency Identification (RFID) cards and readers, QR codes and readers, microcontrollers, electronic displays, and server. In this system, the kanban card is replaced by an RFID card. All workstations in the production process are equipped with RFID readers, microcontrollers, and displays to show relevant instructions to the operator. The microcontrollers are connected to a server to send information in the RFID card scanned by them and the time when the card was scanned. The latter information is used for tracing each of the products produced in each of the workstations. The proposed electronic kanban system was implemented in an assembling process consisting of seven workstations. The system was able to replace the conventional kanban card with RFID and electronic displays and perform the unit tracing capability.*

Keywords—*Kanban, Internet of Things, RFID, production system, smart workstation*

I. INTRODUCTION

Toyota Production System (TPS) is a production system that puts a strong emphasis on efficiency in every aspect of the production process. In contrast to the mass production system that was ubiquitous when TPS was being developed, TPS only performs production activities according to the market needs (pull system) of the product type, quantity, and time to produce a product [1]. With this concept of an efficient and lean system, TPS is also known by the name of Just-In-Time (JIT) and Lean Manufacturing. This concept focuses on value-added production activities with the end goal of better quality and cheaper products. All other activities outside of these are determined as waste [2]. To further improve the proportion of the value-added activities to waste, TPS is supported by fourteen management principles, where kanban is one of them [3].

TPS uses a kanban (which means card or sign in Japanese) system to translate command information into visual instructions for the operators. In TPS, kanban functions as a signal giver. Kanban triggers production activities and the flow of production components so that when a certain process in a workstation is finished, a kanban is released to give the signal for the next workstation to continue the next production step. Here, kanban plays an important role in controlling the production flow. Moreover, kanban enables the control of what product type to be produced, the production quantities, and when the production starts [4]. As one of the pillars of TPS, kanban conforms with the goals of eliminating waste and improving production efficiency. With the development of digitalization, the implementation of kanban today progresses into an electronic form that further strengthens TPS [5].

The application of the Internet of Things (IoT) into production systems started in the 1980s with the implementation of Radio Frequency Identification (RFID) technology [6]. IoT technology, such as wireless sensor networks, RFID, electronic interfaces, and the transfer of information through internet networks and servers into production processes enables seamless access, identification, and control of the manufacturing of production units from raw materials until they are ready to be shipped to customers [7], [8]. Furthermore, the data obtained using IoT can be processed to perform: (i) monitoring of production processes [9], (ii) tracing of production units [10], (iii) analyzing production performance [11], (iv) managing production schedule [12], and (v) obtaining digital twin of the production system [13]. At the level of the production floor, IoT can be applied to improve the performance of the operators through dashboards on electronic displays [14] and perform predictive maintenance on production machines which can reduce the downtime of the machines [15]. With these in mind, we utilize IoT technology to achieve the digitalization of the kanban production system.

This research focuses on the implementation of IoT technology of RFID, QR code, microcontroller, and electronic display in the workstations of a production line, and the technology of internet network and server with database to achieve a digitalization of the kanban system. The production line is an assembling process used by PT. X (a company that manufactures and assembles automotive components) to train new operators on the concept of push and pull in production. The system is composed of workstations that are common in a production system, such as material handling, raw material warehouse, assembly, inspection, and finished goods storage [16], [17]. The production process of this system is managed by the kanban system. The IoT technology is applied to the kanban system and the workstations. We use RFID cards or QR codes as kanban to store information and assign a unique identification for each of the production units. Each of the workstations is equipped with an electronic display (7-segment display or monitor) to show production instructions to the operators based on the information in the card. The use of RFID cards in the kanban system enables sending information to a server automatically. The information on the scanning time of the card at each workstation is sent and stored in a database of the server to perform tracing of the production units on the production floor. This capability extends beyond what the conventional kanban system does.

II. RESEARCH METHOD

This research focuses on integrating IoT technology into a kanban-based production system. This integrated system we call electronic kanban in the subsequent development. The method we chose in this work is Constant Work in Process (CONWIP). Here, the number of work processes for every unit and type is assumed to be the same [18]. This chapter starts with a description of the kanban production system. Then, a design of a production system where the electronic kanban system is applied is described. Lastly, the hardware devices and the software components of the electronic kanban system are selected and developed.

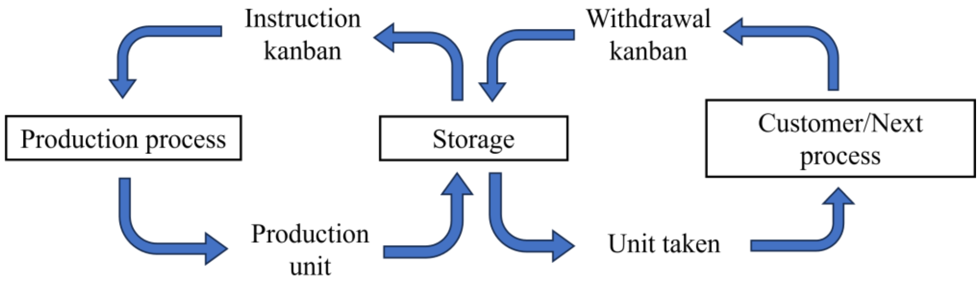


Figure 1. The circulation of withdrawal and instruction kanban in the kanban production system [1].

A. Kanban production system

The kanban system consists of two cards: withdrawal and instruction kanban. An illustration of the kanban system and the circulation of those kanban cards is shown in Figure 1. The description of each of the cards is as follows:

1) Withdrawal kanban

Withdrawal kanban is a kanban card to instruct delivery of finished goods according to a customer’s order or heading toward the next production process where the process uses products from a prior production line [19]. In the Just-In-Time system, every time a withdrawal kanban is received, the production line has to provide products with the same kind and amount as ordered. The requested products are obtained from a storage that stores finished goods from the line production, and then they are given to the customer or the next production process (see the right side of Figure 1). Furthermore, the withdrawal kanban is translated into instruction kanban to instruct production in a production line connected to this kanban system [1]. Every time withdrawal kanban is used to take a finished good, the instruction kanban of the unit rolls again in the production line to produce the same unit.

2) Instruction kanban

Instruction kanban is a kanban card used to instruct production processes according to a received order on a production line [19]. This kanban translates order into production instructions. It starts to roll in a production line after it is exchanged with the withdrawal kanban in the storage. Every product type has different instruction kanban. It sticks with a work-in-progress (WIP), from one workstation to the next one, until the unit is finished and stored in storage (see the left side of Figure 1).

To achieve digitalization of the kanban production system, the information contained in each of the kanban cards has to be stored digitally. On the withdrawal kanban, a QR code is added to it which contains a summary of the order information of the kanban. The addition of the QR code enables the recording of the information to a database seamlessly by sending the information as the code is scanned. Besides using the QR code, an RFID card is employed to replace the instruction kanban. The RFID card stores important information about a production unit, such as unit ID and the product type of the unit. The card is scanned on each of the workstations in the production line to show instructions according to the product type on an electronic display. In addition to replacing the instruction kanban, the utilization of the RFID card, RFID scanner, and microcontroller (with a communication module) enables the tracing of a production unit. The unit tracing capability is discussed further in Chapter II.D.

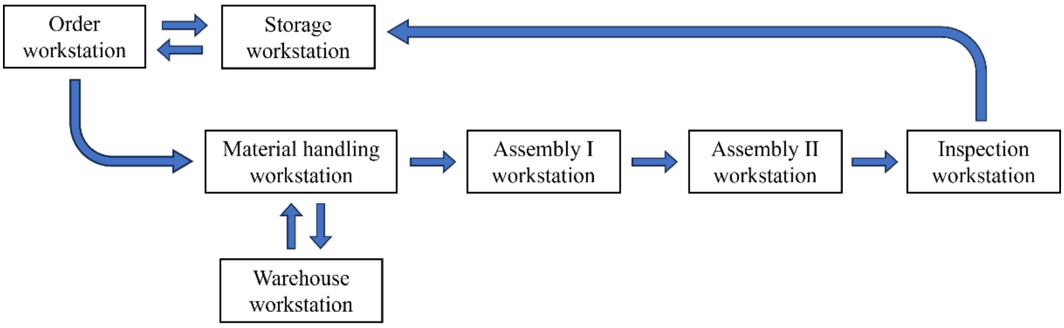


Figure 2. A production system where the electronic kanban system is applied.

B. Design of Production System

A block diagram of the production system is shown in Figure 2. This system is used in a training of push/pull production system in PT. X (a company that produces automotive components). The electronic kanban system is applied to this production system. It is composed of five types of workstations: order, storage, material handling, warehouse, and assembly. Assembly I, Assembly II, and Inspection workstations in Figure 2 belong to the assembly workstation type. The description of each workstation type, the circulation of kanban cards on the system, and the integration of IoT devices at each workstation as building blocks of the proposed electronic kanban system are elaborated as follows:

1) Order workstation

It is the first workstation in the production line. Here, the operator obtains a withdrawal kanban containing the information of the product ordered by a customer. In this research, we assume this kanban is obtained by the operator as the customer comes to take the requested product. The operator brings the kanban to the storage workstation and takes the finished goods according to the kanban. The exchange of the withdrawal and instruction kanban happens in this storage rather than in the storage workstation to shorten the movement of the operator. The instruction kanban attached to the finished good is taken and exchanged with the withdrawal kanban before the product is given to the customer. The obtained instruction kanban is then given to the operator in the material handling workstation to start a new production process according to the instruction kanban.

In the electronic kanban system, this workstation is equipped with a QR scanner connected to a microcontroller. As the withdrawal kanban is obtained, the operator scans a QR code in the kanban. As the product is obtained from the storage, the instruction kanban in the form of an RFID card is stored in a pile of the RFID cards in the material handling workstation.

2) Storage workstation

It is a workstation where the finished production units are stored. The operator sends the unit after being checked in the inspection workstation to this workstation. Moreover, the operator from the order workstation takes a unit according to the withdrawal kanban here.

In the electronic kanban system, this workstation is equipped with an RFID reader, a microcontroller, and electronic displays to show the number of units stored for each product type. Here, we use two RFID readers to obtain the scanned time of the RFID card as the unit goes in and out of the workstation, and we use several 7-segment displays for the electronic displays of the amount of stored product type.

3) Material handling workstation

It is the workstation where the production process starts and the production materials are gathered. The operator of this workstation obtains the instruction kanban from the operator of the order workstation. The operator takes a tray to store production materials, WIP, and the finished goods. The operator attaches the kanban to the tray. Next, the operator heads to the warehouse workstation to obtain production materials. After all of the materials needed are in the tray, the operator hands over the tray to the operator of the first assembly workstation.

In the electronic kanban system, the operator takes an RFID card from a pile of RFID cards and writes it using an RFID writer. This RFID card functions as the instruction kanban of the unit that is going to be produced. One of the pieces of information written is a unique unit ID to support the function of unit tracing. The card is placed inside the tray of the production unit.

4) Warehouse workstation

It is the workstation where all of the materials needed by a production line are stored. The stored materials can be raw materials or goods produced by other production processes. The operator takes the materials according to the instruction kanban. They are placed inside the tray obtained in the material workstation.

In the electronic kanban system, this workstation is equipped with an RFID reader, microcontroller, and electronic displays. The reader is used to read the instruction kanban in the form of an RFID card. The information on the production materials is shown on several 7-segment displays attached to each of the material containers. This way of displaying information can be designed to support an anti-fault mechanism, i.e., a system/mechanism that helps the operator avoid mistakes in obtaining the materials. Here, the 7-segment displays turn on and display numeric characters according to the product type.

5) Assembly workstation

It is the workstation where assembly processes are carried out. In general, there are more than one assembly workstation in a production line. In each assembly workstation, the operator performs assembly steps according to the assembly tasks of the product type in the instruction kanban. The assembly tasks are usually printed and attached to the assembly table of the workstation. After the operator is finished with the tasks, he/she gives the WIP to the operator in the next assembly workstation. At the end of this assembly line, there is an inspection workstation where the finished WIP is examined. After passing the inspection, the finished good is transported to the *storage workstation*.

In the electronic kanban system, the workstation is equipped with an RFID reader, a microcontroller, a computation unit, and a monitor to show the assembly tasks according to the product type of the WIP and the position of the workstation in the assembly line. By utilizing the display, the instruction tasks are not printed and attached to the workstation anymore. The medium to display the assembly tasks is not limited to text or image, but also in the form of video. The choice of medium depends on the capability of the computation unit attached to the RFID reader.

C. Hardware Devices of Electronic Kanban System

The IoT devices involved in the electronic kanban system are RFID reader/writer MFRC522, QR code reader, 7-segment display, monitor, NodeMCU ESP8266, ESP32, dan Raspberry Pi. These devices are utilized in each of the workstations according to the operations done in the workstation. For example, in the warehouse workstation, the operations done are the operator obtains materials according to the product type of the unit to be produced. In the electronic kanban system, the RFID card is scanned, and then the information of the materials to obtain are displayed on electronic displays. To achieve this objective, we use an RFID reader, a microcontroller in the form of ESP32, and several 7-segment displays attached to each of the material containers to display the quantity information. The summary of the IoT devices utilized on other workstations is shown in Table 1, which can be inferred from Chapter II.B.

Table 1. List of IoT devices in the workstations.

No.	Workstation	IoT Devices
1	Order	QR scanner, NodeMCU
2	Storage	RFID reader, NodeMCU, 7-segment display
3	Material Handling	RFID writer, NodeMCU
4	Warehouse	RFID reader, ESP32, 7-segment display
5	Assembly/Inspection	RFID reader, NodeMCU, Raspberry Pi, monitor

D. Design of Software of Electronic Kanban System

The software of the electronic kanban system consists of two parts: the software on each of the workstations and the software on the server. They are described next.

1) Workstation software

The microcontroller in each of the workstations is programmed a software to do functions of the workstation as described in Chapter II.B. In the material handling and assembly workstation, the instructions are programmed in the HTML code and then displayed on a web interface. Besides doing the functions, the electronic kanban system supports the unit tracing function of each of the production units. On each workstation, every time a QR code or RFID card is scanned by the microcontroller, the timestamp of the scanning, the location of the scanning, and the information inside the card are sent to a server and stored for each of the units. The description of the server is in the next section. The summary of the functions done by the software of each of the workstations is displayed in Table 2.

Table 2. List of functions of the software of each of the workstations.

No.	Workstation	Software Functions
1	Order	To read QR code, and to send timestamp and QR code information to a server.
2	Storage	To read RFID cards, to display the quantity of each product type on 7-segment displays, dan to send timestamp, location, and card information to a server.
3	Material Handling	To show instructions on writing an RFID card on a monitor, to write the RFID card, and to send timestamp, location, and card information to a server.
4	Warehouse	To read RFID cards, to show the quantity of the materials on several 7-segment displays according to the product type, and to send timestamp, location, and card information to a server.
5	Assembly/Inspection	To read RFID cards, to show assembly tasks on a monitor, and to send timestamp, location, and card information to a server.

2) Server software

The electronic kanban system has a server with a database where the unit tracing function is performed. In this database, the information of the unit ID, product type, and the timestamp of each unit when being scanned at each of the workstations is stored. The timestamps are sent by the microcontroller in each workstation immediately when the QR code or RFID card is scanned. The server stores the received timestamp according to the information on the unit ID.

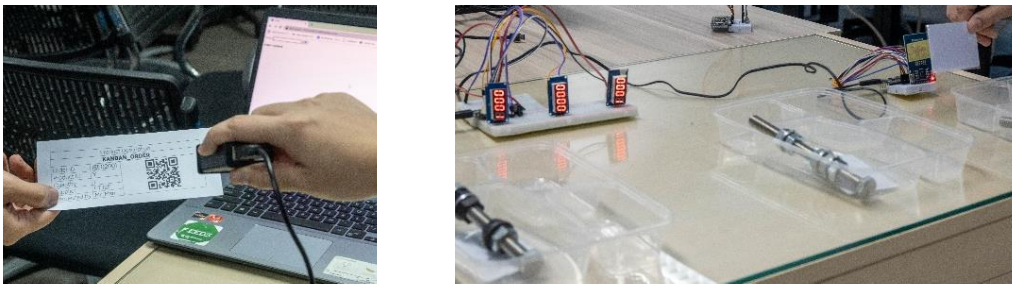
The software of the server is developed with Django framework and Django REST Framework library in Python language with SQLite database [20]. The implementation of the database uses Object Relational Mapping (ORM) from Django. The data inside the database can be pulled and stored by the application. This data transaction is done in two interfaces: web interface and Application Programming Interface (API). The web interface is used when direct communication between the server and a user (human interface) is needed. This happens in the material handling and assembly workstations. In Django, this can be achieved using the render function to read and show HTML code. The API is used as a communication intermediary between the server and the microcontroller in every workstation. Moreover, API is also used to communicate between the web interface and the database. All the needs to store and pull the data from and to the database are done through the API.

III. RESULTS AND DISCUSSION

An implementation of the electronic kanban system on a production line shown in Figure 2 is explained next. The implementation of this system together with the production line was done in the IoT laboratory in Institut Teknologi Calvin. In this production line, we produced three product types as shown in Figure 3. Each of the products consists of some combination of bolts, silver or black nuts, and silver or black washers. The electronic kanban system is designed to accommodate these product types. The RFID cards used in this experiment are Mifare 13.56 MHz.

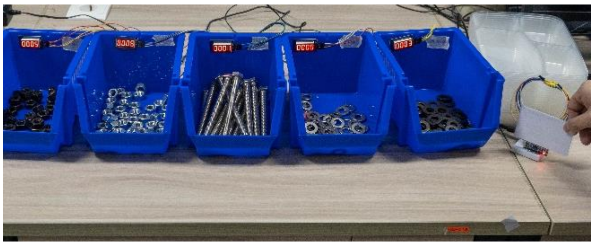
Figure 3. A photograph of three product types to be produced in the production system.

Photographs of the workstations in this production line and the IoT devices that support the electronic kanban system are shown in Figure 4: (a) order workstation, (b) storage workstation, (c), material handling workstation, (d), warehouse workstation, (e) assembly workstation, dan (f) inspection workstation. Each of the workstations performs its functions as described in Chapter II.B. In the order workstation (Figure 4a), a withdrawal kanban which contains a QR code was scanned successfully by a QR scanner that is connected to a laptop. In the storage workstation (Figure 4b), a finished good was obtained according to the customer's order in the withdrawal kanban. The RFID card of the unit was scanned successfully as the unit was out of the workstation, dan the 7-segment displays that show the quantity of remaining units for each of the product types were updated accordingly. In the material handling workstation (Figure 4c), the RFID card to the unit to be produced was written successfully with the RFID writer connected to a microcontroller and a laptop to input information to the card. In the warehouse workstation (Figure 4d), the RFID card was read successfully, and the 7-segment displays attached to each of the material containers were able to show the amount of each of the materials to be obtained according to the product type of the card. In the assembly workstation (Figure 4e), the RFID card was read successfully, and a monitor was able to show the assembly tasks according to the position in the production line and the product type of the card. Lastly, in the inspection workstation (Figure 4f), the RFID card was read successfully, and a monitor was able to show the inspection tasks according to the product type of the card.

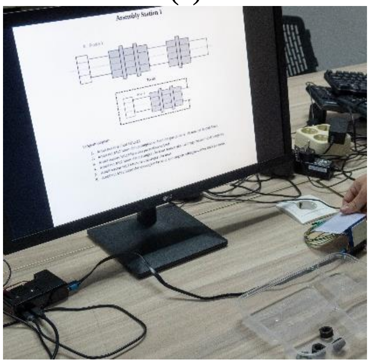


(a) (b)

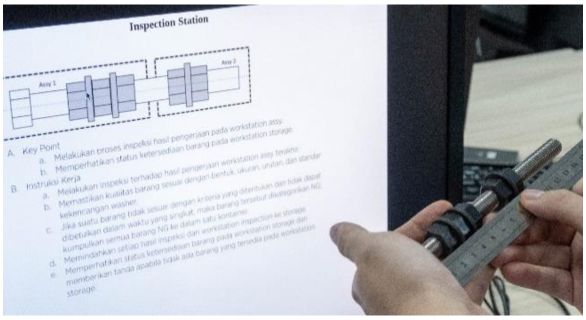
(c)



(d)



(e)



(f)

Figure 4. Photographs of the workstations in the electronic kanban system.

A screenshot of the database created to perform unit tracing is shown in Figure 5. Timestamps, i.e., the time of scanning of QR codes and RFID cards, of each of the workstations are captured, sent, and stored in the database according to the unit ID (that is, product code in Figure 5). For the latest three units, the timestamps in the order workstation and the delivered timestamp in the storage workstation were not yet captured because a customer had not arrived to pick up his/her order. These timestamp data can be further processed to determine the lead time and analyze the performance of each of the workstations in the production line.

ID	PRODUCT CODE	UNIT TYPE	TIME ORDER	TIME MATERIAL HANDLING	TIME WAREHOUSE	TIME ASSY1	TIME ASSY2	TIME STORAGE	TIME DELIVERED
9	Y003	Y	-	Jan. 20, 2024, 10:57 a.m.	Jan. 20, 2024, 11 a.m.	Jan. 20, 2024, 11:02 a.m.	Jan. 20, 2024, 11:04 a.m.	Jan. 20, 2024, 11:08 a.m.	-
8	Z003	Z	-	Jan. 20, 2024, 10:47 a.m.	Jan. 20, 2024, 10:50 a.m.	Jan. 20, 2024, 10:52 a.m.	Jan. 20, 2024, 10:54 a.m.	Jan. 20, 2024, 10:57 a.m.	-
7	X003	X	-	Jan. 20, 2024, 10:38 a.m.	Jan. 20, 2024, 10:42 a.m.	Jan. 20, 2024, 10:44 a.m.	Jan. 20, 2024, 10:47 a.m.	Jan. 20, 2024, 10:52 a.m.	-
6	Z002	Z	Jan. 20, 2024, 10:45 a.m.	Jan. 20, 2024, 10:27 a.m.	Jan. 20, 2024, 10:28 a.m.	Jan. 20, 2024, 10:31 a.m.	Jan. 20, 2024, 10:33 a.m.	Jan. 20, 2024, 10:36 a.m.	Jan. 20, 2024, 10:47 a.m.
5	Y002	Y	Jan. 20, 2024, 10:55 a.m.	Jan. 20, 2024, 10:18 a.m.	Jan. 20, 2024, 10:21 a.m.	Jan. 20, 2024, 10:23 a.m.	Jan. 20, 2024, 10:26 a.m.	Jan. 20, 2024, 10:28 a.m.	Jan. 20, 2024, 10:30 a.m.
4	X002	X	Jan. 20, 2024, 10:35 a.m.	Jan. 20, 2024, 10:07 a.m.	Jan. 20, 2024, 10:08 a.m.	Jan. 20, 2024, 10:10 a.m.	Jan. 20, 2024, 10:13 a.m.	Jan. 20, 2024, 10:16 a.m.	Jan. 20, 2024, 10:36 a.m.
3	Z001	Z	Jan. 20, 2024, 10:25 a.m.	Jan. 20, 2024, 9:52 a.m.	Jan. 20, 2024, 9:55 a.m.	Jan. 20, 2024, 9:57 a.m.	Jan. 20, 2024, 9:59 a.m.	Jan. 20, 2024, 10:02 a.m.	Jan. 20, 2024, 10:27 a.m.
2	Y001	Y	Jan. 20, 2024, 10:15 a.m.	Jan. 20, 2024, 9:44 a.m.	Jan. 20, 2024, 9:46 a.m.	Jan. 20, 2024, 9:48 a.m.	Jan. 20, 2024, 9:50 a.m.	Jan. 20, 2024, 9:53 a.m.	Jan. 20, 2024, 10:17 a.m.
1	X001	X	Jan. 20, 2024, 10:05 a.m.	Jan. 20, 2024, 9:37 a.m.	Jan. 20, 2024, 9:39 a.m.	Jan. 20, 2024, 9:41 a.m.	Jan. 20, 2024, 9:44 a.m.	Jan. 20, 2024, 9:48 a.m.	Jan. 20, 2024, 10:07 a.m.

Figure 5. A screenshot of the database for unit tracing.

From this experiment, we can see that this electronic kanban system has several advantages over the conventional kanban system as follows: (i) it enables the production system to support more product types because the information of the product is stored digitally, (ii) it can show information and instructions of a production unit through an appropriate display digitally, (iii) it reduces operator faults by only displaying information and instructions according to the product type, and (iv) it is equipped by unit tracing capability which can be used to improve the performance of the production system using the data obtained by the server.

IV. CONCLUSION

The proposed electronic kanban system has been implemented into a simple production line. QR codes and RFID cards can be used to replace the conventional withdrawal and instruction kanban cards. IoT technology, such as QR and RFID readers, microcontrollers, and electronic displays, can be applied to each of the workstations to achieve digitalization of the kanban system. Furthermore, unit tracing capability has been implemented by sending the information of the scanned RFID card in each workstation to the server. One possible direction of this research is to extend this electronic kanban system to accommodate sub-assemblies in the production line. Another direction is to process and analyze unit tracing data to improve the performance of a production line.

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