Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 63 (2017) 465 – 470

www.elsevier.com/locate/procedia

The 50th CIRP Conference on Manufacturing Systems

Construction of a virtual production line including a buffer for simulation of electric power consumption

Sota Matsumoto[a,]*, Michiko Matsuda[a]

[a]Kanagawa Institute of Technology, 1030 Shimo-ogino, Atsugi-shi, Kanagawa, 243-0292, Japan

* Corresponding author. Tel.: +81-46-291-3213; fax: +81-46-242-8490. *E-mail address:* sotaplusplus@gmail.com

Abstract

The digital eco-factory has been proposed by the authors for simultaneous simulation of green performance, productivity and manufacturability. The digital eco-factory is constructed on a virtual production line modelling an actual production line. The virtual production line has been constructed by sequentially connecting machine agents which have been generated from their behaviour model. For example, a virtual PCA (Printed Circuit Assembly) line was constructed by connecting sequentially a solder paste printing machine, two or three electronic part mounters, reflow furnace and testing machine. In this virtual PCA line, the connection between machines is not considered exactly. Usually the processing time for a job for each machine is different. It means usually there is a residence time before proceeding to the next process. For smooth production processing, it is important to control the production flow. In this paper, behaviour of a buffer is modelled and a buffer agent is generated. Buffer agents are put in the intervals between machine agents. A buffer agent controls flow of material/product on the virtual line by communicating with other machine agents. A machine buffer has activities such as storing, loading and unloading. The buffer adjusts the start timing of the job for material/product. When the next machine which processes the next step of the job is occupied, the buffer agent stops to feed material/product. When the buffer storage is full, the buffer agent lets the previous position machine agent know. Buffer function is important to simulate production condition with high accuracy. Through the construction of a virtual PCA line including buffers, the importance of a buffer agent is shown.

Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems

Keywords: machine behavior modeling, multi agent system, buffer agent, viraul factory, virtual production control ;

1. Introduction

In modern production, a manufacturer should consider sustainability of the global environment in addition to productivity[1]. For sustainable manufacturing, a pre-view of environmental items such as power consumption of a production machine and illumination, material consumption, and emissions of CO2 are required. Generally, in planning for production, a simulation system is used for considering productivity, sustainability and so on. There are various types of simulation systems.

Recently, cyber physical production systems have been prepared and have become a big trend[2-4]. The cyber physical production system connects the virtual factory with the real factory. At the real factory, a machine is connected with the internet and sends out current machine conditions. In the virtual factory, these large data provided by the machines are used for constructing a precise simulation procedure. There is an example of using a cyber physical production system[4]. German industry, government and academia have proposed industry4.0[5,6]. General Electric, an American company, has proposed the Industrial Internet. Both construct a virtual factory on a computer and use it for virtual manufacturing.

The Digital Eco-Factory has been proposed by the authors for simultaneous simulation of green performance, productivity and manufacturability[7]. The Digital Eco-Factory is constructed on a virtual production line modelling an actual production line. The virtual production line has been constructed as a multi agent system and sequentially connecting agents which have been generated from their behaviour model.

Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems
doi:10.1016/j.procir.2017.03.107

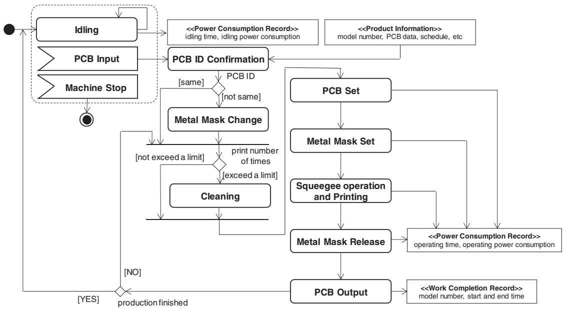


Fig. 1. Activity diagram of solder paste printing machine.

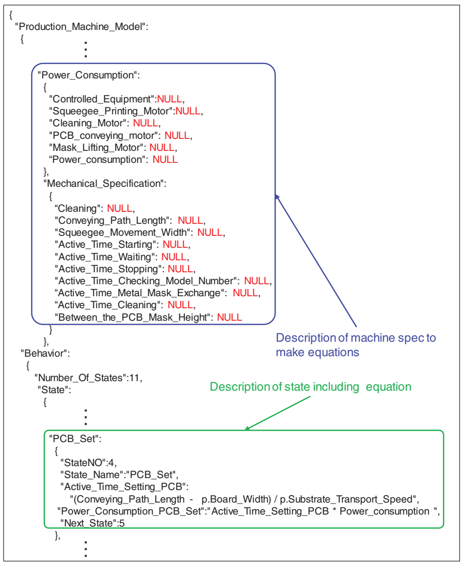


Fig. 2. Template of solder paste printing machine described by JAON.

Table 1. Examples of equations embedded in the e-catalogue of the machine.

activity	Equations for power consumption calculation
Starting	Power Consumption Starting[kWh] = Active Time Starting[h] × Controlled Equipment[kW]
Waiting	Power Consumption Waiting[kWh] = Active Time Waiting[h] × Controlled Equipment[kW]
PCB ID Confirmation	Power Consumption PCB ID Confirmation[kWh] = 0
Metal Mask Change	Power Consumption Metal Mask Exchange[kWh] = Active Time Metal Mask Exchange[h] × Controlled Equipment[kW]
PCB Set	Active Time PCB Set[s] = (Conveying Path Length[mm] − p.Board Width[mm]) ÷ p.Conveying Speed[mm/s] Power Consumption PCB Set[kWh] = Active Time PCB Set[h] × PCB Conveying Motor[kW]
Metal Mask Set	Active Time Metal Mask Set[s] = Between the PCB Mask Height[mm] ÷ o.Mask Elevating Speed[mm/s] Power Consumption Metal Mask Set[kWh] = Active Time Metal Mask Set[s] × Mask Lifting Motor[kW]

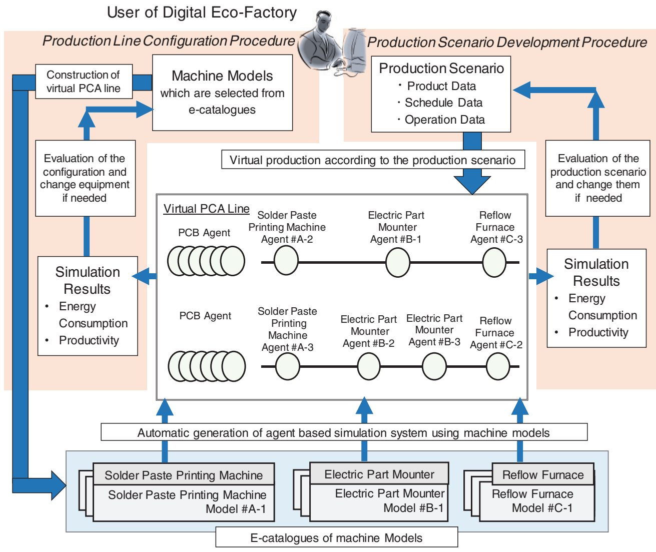


Fig. 3. System structure of dev

Usually, there is a difficult for the user of a production simulation system such as a production system designer and operator to construct the virtual production line such as writing a software program of agents. Then, it is proposed that a user constructs a virtual production line by selecting an adequate machine model from the repository. A machine model can be called an e-catalogue of a machine and the repository of machine models can be called an e-catalogue library[8,9]. The difference between a Digital Eco-Factory and the existing simulation tool[10-12] is the method of construction of the virtual production line. When a user wants to simulate their production, the existing simulation tool usually requires to describe models of the machine on the production line. On the other hand, a user of the Digital Eco-Factory can configure the virtual production line by selecting a machine model which is called e-catalogue. As a result, the user of the Digital Eco-Factory can change the configuration of the virtual production line easily and flexibly.

In this paper, a buffer is introduced for more precise simulation of the virtual production. In other words, a buffer behaviour model is newly added as a machine model to the repository. A buffer has functions for stocking and supplying semi-finished products. The behaviour of a buffer is modelled and a buffer agent is generated based on the model. Buffer agents are put in the intervals between other machine agents. A buffer agent controls the flow of material/product on the virtual line. Through the construction of a virtual PCA line including buffers, methods for behaviour modelling of a buffer and the construction of a virtual production line including buffers as multi-agent system, are discussed.

2. Requirements for a buffer

2.1. Machine model embedded equations for power consumption calculation

To calculate power consumption, there is a requirement to model the behaviour of a machine. The behaviour model can be described by an activity diagram of UML. As an example, the activity diagram for the behaviour model of a solder paste printing machine is shown in Fig. 1. One product is produced through these activities in the solder paste printing machine.

Each activity is embedded with equations for calculating active time and power consumption to provide a high accuracy simulation. Table 1 shows examples of these equations. These equations include parameters which start by an “o.” or “p.”. When the simulation is executed, values of parameters are provided by the production scenario. The others parameters are provided by the machine specification data.

Table 2. Required functions for a buffer in virtual production

physical buffer	virtual buffer	detail of function
Stock (Storage)	Communication	Notification whether stocker is full or not
		Acceptance of stocking request
	Recording (Calculation)	Stocking- in time
		Number of stocks
		Power consumption
Supply (Discharge)	Communication	Notification whether stocker is empty or not
		Acceptance of supply request
	Recording (Calculation)	Supplying time (sending-out time)
		Number of stocks
		Power consumption

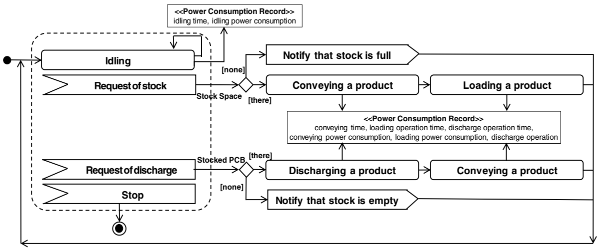


Fig. 4. The activity diagram for a buffer.

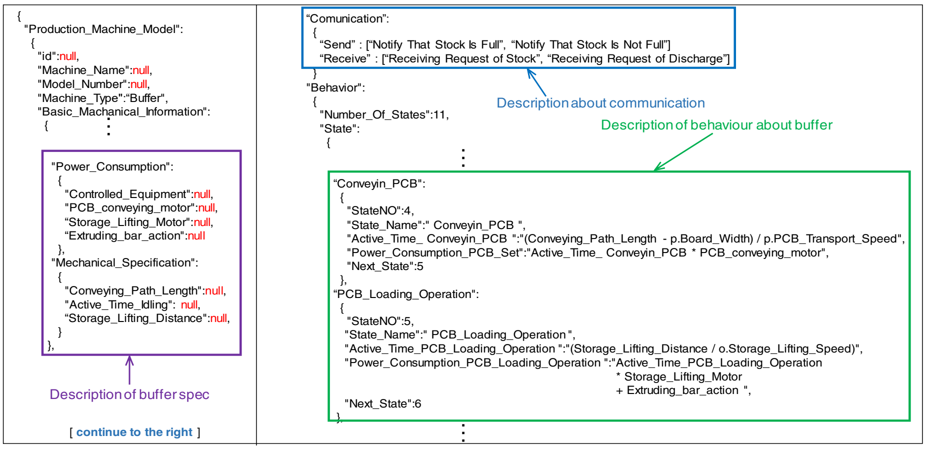


Fig. 5. The template of a buffer.

Machine models with equations are described using a data description language such as JSON (JavaScript Object Notation) or XML. This description is called a template which is prepared corresponding to machine type. The template of a solder paste printing machine described by JSON is shown in Fig. 2. Descriptions of machine specification are used for creation of power consumption equations. An equation is described for each state in the description of behaviour. An e-catalogue is created by filling up a template by concrete values corresponding to the machine[8].

2.2. Developed Digital Eco-Factory for PCA

As an example, a Digital Eco-Factory for a PCA is developed[7-9]. Fig. 3 shows the conceptual structure of the developed Digital Eco-Factory for the PCA. The Digital Eco-Factory is a vehicle of simulation that takes into consideration unique values related to the production that can be executed for the first time by inputting a production scenario after selecting machines and creating a model of a virtual production line. To use the Digital Eco-Factory, at first, the operator selects a machine model for construction of a virtual production line from e-catalogues. The virtual production line is automatically constructed as a multi-agent system and each machine is implemented as a software agent. Second, the operator inputs a production scenario as product data, schedule data and operation data. Virtual manufacturing is executed and simulation results are output. Using output data, the operator evaluates simulation results in order to balance productivity and green performance. Balance is considered from two viewpoints. One viewpoint is a line construction view. In this viewpoint, the operator evaluates power consumption by changing line component machines. Another viewpoint is the production scenario view. In this view, the operator evaluates power consumption by changing scheduling data and operation data.

2.3. Requirements for buffers on virtual PCA line

In the Digital Eco-Factory developed so far, there is no intermediate storage between machines. Therefore, various problems occurred. These were:

- Virtual product waits in unknown space until the next machine accepts the next task
- A virtual line cannot adjust to the product flow rate
- A virtual line does not stop until there is nothing more to produce
- Movement on the virtual production line differs from the actual line movement, as a result, it affects the accuracy of the simulation

To solve the above problems, buffer functions are required. A buffer has activities such as storing, loading and unloading. The buffer adjusts the start timing of the task for the material/product. When the next machine which processes the next step task is occupied, the buffer stops to feed the material/product. When the buffer storage is full, the buffer

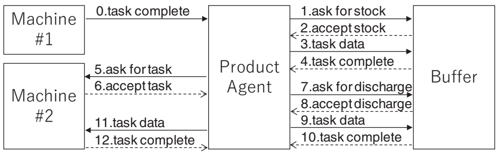


Fig. 6. Example diagram of communication between machines.

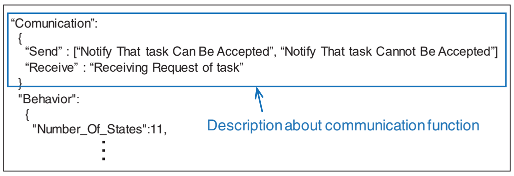


Fig. 7. Example of e-catalogue of solder paste printing machine including communication description

lets the previous machine know. The buffer function is important to simulate production condition with high accuracy.

3. A buffer model

3.1. Functions of a virtual buffer

Requirement functions for a virtual buffer in a virtual production line are shown in Table 2. Compared to just modelling of machines, not only implementation of calculation equations but also implementation of communication functions with others are required as well. There are two communication functions implemented for both transmission and reception. For the transmission function which is related to the storage function, it furnishes its state of whether it is fully occupied or not. For the reception function which is related to discharge, a request to supply the unfinished product to the next machine from the stocker are received. In the recording function, not only calculation of the action time and power consumption up to now but also a calculation of the number of products inside the stocker is added.

3.2. Behaviour modelling of a buffer

The behaviour model of the buffer is described by the UML activity diagram as shown in Fig. 4. When the buffer starts up, it shifts to the idle state. When receiving a request for stock, it calculates the number of unfinished products in the stocker. If there is space, conveying the product to the stocker and loading the product to the stocker are done. If there is no space, the notification that the stocker is full is sent out. When receiving a request for discharge, the number of products in the stocker is calculated. If there is a product in the stocker, discharging the product from the stocker and conveying the products to the next machine is performed. If there is no product, notification that the stocker is empty is sent out.

To produce an e-catalogue for each concrete physical buffer, a template is necessary. A template is a frame which describes the buffer model using a data description language such as JSON and XML based on a UML model. The template of the buffer described by using JSON is shown in

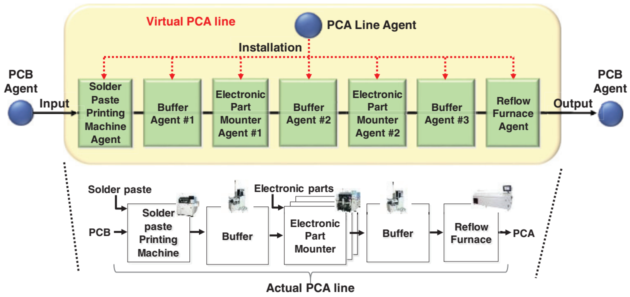


Fig. 8. Structure of the virtual PCA line including buffers.

Fig. 5. As in the machine model, the template is roughly divided into two parts. One is the part for describing static specifications of the buffer. The other is the part for describing behaviour. A description concerning communication is added. The buffer agent is automatically generated based on the e-catalogue.

4. Construction of the virtual production line including buffers

4.1. Addition of communication function to machine models

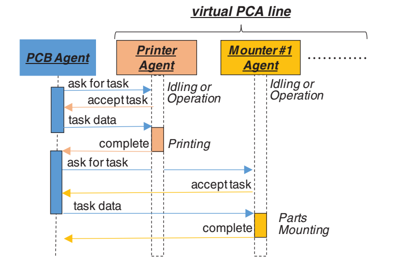
On the virtual production line in the Digital Eco-Factory, a product agent leads the execution of the processing to complete itself as final product. The centre of communication is a product agent. The product agent is created according to the production schedule when executing the simulation. The diagram for the communication example with machines is shown in Fig. 6. In this figure, the communication for requesting storage to the buffer and the communication for requesting discharge to the next machine are shown. First, the product agent asks the buffer for storage. Second, the product agent asks for the work for the machine to receive the next task. Third, the product agent requests the buffer to discharge itself from the buffer. Finally, the product agent proceeds to the next task.

In order to achieve the above communications, it is necessary to add the communication function to machine agents, just as was done for a buffer. As an example, added description for communication in an agent of solder paste printing machine is shown in Fig. 7. Machines have a function to notify that a task can be accepted or to notify that a task cannot be accepted. In addition, machines have a function to receive the request for a task.

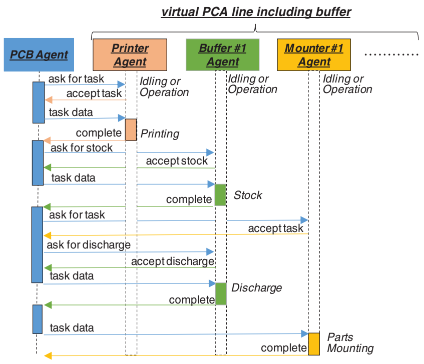
4.2. Construction of the virtual PCA line including buffers using e-catalogues

Each machine agent is configured automatically based on the e-catalogue which is selected by the operator of the Digital Eco-Factory. Moreover, the generated machine agents are sequentially connected to form a virtual production line. The product agent carries out the processes of the virtual production to transform itself into the completed product by communicating with machines on the production line.

The structure of the virtual PCA line including buffers is shown in Fig. 8. Buffer agents are put in the intervals between machine agents. The PCA line agent manages structuring the



(a) Communication sequence of virtual PCA line without buffer



(b) Communication sequence of virtual PCA line including buffers

Fig. 9. Comparison of production control sequence.

virtual PCA line. The PCA line agent activates machine agents. The PCA line agent has information about the structure of the virtual line such as connecting relations among machine agents. In the virtual PCA line, the product agent is called the PCB (Printed Circuit Board) agent.

A comparison of UML sequence diagrams for virtual PCA line without buffers and for virtual PCA line including buffer is shown in Fig. 9. Both diagrams show communication from the time when the PCB agent asks for the first task to the printer agent. In Fig.9. (a), the PCB agent issues a task request to the printer agent and it receives a completion report from the printer agent, then immediately, the PCB agent issues a task request to the mounter agent and receives a completion report from the mounter agent. In Fig.9. (b), the PCB agent issues a task request to the printer agent, and when it receives a completion report from the printer agent, it issues a storage request to the buffer agent. When receiving a storage completion report from the buffer agent, the PCB agent issues a request for task to the mounter agent. When the request is accepted, the PCB agent issues a discharge request to the buffer agent. When the discharge is completed, the task data is handed over to the mounter agent and the completion report is received.

5. Operation of the virtual production line

5.1. Operation of the virtual PCA line including buffers

When the stocker of the buffer is "full", the operation on the virtual production line is shown in Fig. 10. In this figure, the buffer agent assumes that the number of storable unfinished PCBs is one. There are two PCB agents. In other words, two PCBs are being produced. One PCB agent asks

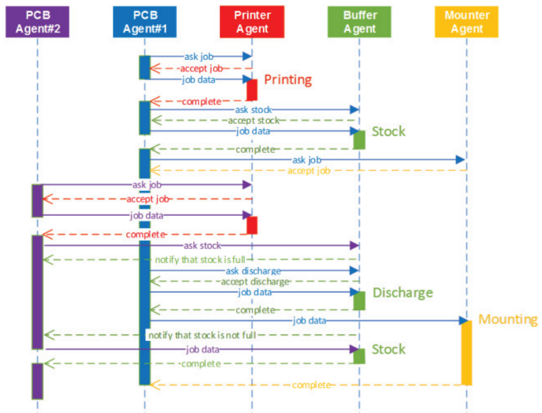


Fig. 10. Operation when buffer is full on virtual production line.

the printer agent for the task. When the acceptance is returned, the task data is transmitted. When the completion report arrives from the printer agent, it issues a storage request to the buffer agent. When the completion report comes back, the PCB agent asks the mounter agent for the task. At this moment, since the printer agent is free, the other PCB agent requests the printer to do the task. When the completion report is returned from the printer agent, the other PCB agent asks the buffer agent to store. However, at this moment, the other PCB agent is notified that the buffer agent cannot be stored because it is "full". When the first PCB agent receives an acceptance from the mounter, it issues a discharge request to the buffer agent. When the buffer agent discharges according to the request, the buffer agent has one free space at the stocker. The second PCB agent that is on standby is notified that the buffer agent has free space to store the second PCB.

5.2. Trial simulation of electric power consumption using virtual PCA line including buffers

Trial simulations are executed using constructed virtual PCA lines including buffers. An example of the display for electric power consumption simulation is shown in Fig. 11. The upper part in this figure shows constructing the PCA line. The lower part shows the time series change of power consumption for each machine. On the right side are messages which the buffer exchanged with other machines and PCB agents. These messages indicate that the buffer controls the production line.

To compare a virtual production line with and without buffer, trial simulations are also executed using constructed virtual PCA lines without buffers as shown in Fig. 12. In the real line, even when the product is waiting between the machine and the next machine, power consumption occurs because product is stored in the buffer. However, since there was no buffer, power consumption was not counted at the virtual production line of Fig. 12. By implementing the buffer agent, power consumption during storing in the buffer is considered like shown in Fig. 11. Moreover, because of the buffer, the waveform of power consumption became more realistic. In the simulation without buffer, a machine keeps making products until the production plan is fulfilled. So the products accumulate indefinitely between the machine and the

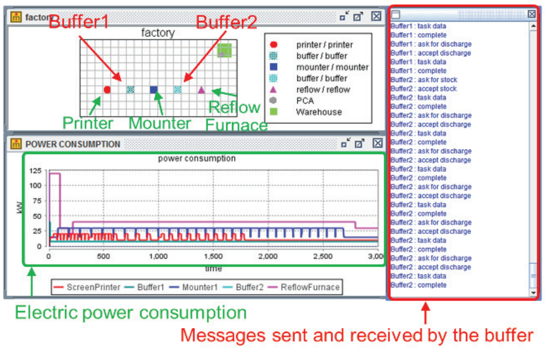


Fig. 11. Example display of electric power consumption simulation using virtual PCA line including buffer.

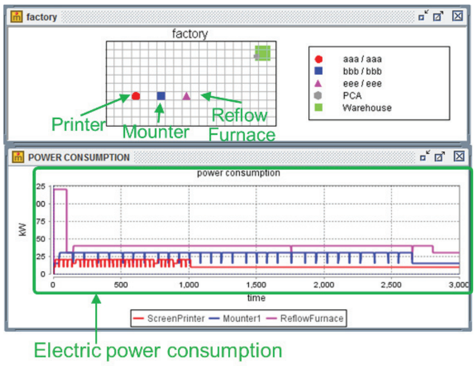


Fig. 12. Example display of electric power consumption simulation using virtual PCA line excluding buffer.

next machine. And an unrealistic waveform of power consumption that the machine always keeps moving is shown. In the simulation with buffer, the simulation considering capacity between the machine and next machine is executed. Therefore, the waveform of power consumption in which the machine waits when the capacity between machine and next machine become full is confirmed.

At this moment, trial uses are being performed in industries. Although the timing at which power consumption occurs is accurate, the numerical precision of power consumption is not strict. It is said that the trend is more important than the numerical strictness about power consumption and that this system is practically usable.

6. Conclusions

A buffer function was newly added to the virtual production line for a more accurate simulation of production control. In order to implement the buffer, the behaviour of the buffer is modelled. Using this behaviour model for a buffer, the template for creating an e-catalogue of the buffer is written in a data description language called JSON. Descriptions for communication functions were newly added to e-catalogues for buffers and other machines. The power consumption simulation was executed in the virtual PCB production line including the buffer agents showed that the buffer agents control production flow by communicating with other machine agents and PCB agents. Based on the above results, when simulating a virtual production line with high accuracy, buffers with communication functions are necessary.

Acknowledgements

This work is supported by JKA and its promotion funds from KEIRIN RACE. The authors thank JKA. And also, the authors thank members of Technical Committee " DEcoF (Digital Eco Factory) " (2012. Oct. -) by FAOP (FA Open Systems Promotion Forum) in MSTC (Manufacturing Science and Technology Centre), Japan for fruitful discussions and their supports. The authors are grateful to Dr. Udo Graefe, retired from the National Research Council of Canada for his helpful assistance with the writing of this paper in English.

References

[1] Sarkis J. Manufacturing's role in corporate environmental sustainability – concerns for the new millennium, International Journal of Operations & Production Management. Vol. 21 Iss: 5/6, 2001, p. 666-686.

[2] Monostori L. Váncza J., Kumara S. Agent-based systems for manufacturing, CIRP Annals-Manufacturing Technology, vol. 55, no. 2, , 2006, p.697-720.

[3] Monostori L. Cyber-physical production systems: Roots, expectations and R&D challenges, Procedia CIRP vol.17 (Special Issue on) 47th Conference on Manufacturing Systems, Elsevier, 2014. p.9-13.

[4] Leitão P., Colombo W. A., Karnouskos S. Industrial automation based on cyber-physical systems technologies: Prototype implementations and challenges, Computers in Insudtry, Vol81(2016), p.11-25.

[5] Lee. J, Bagheri B., Kao H. A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems, Manufacturing Letters.Vol3, p.18-23, (2015).

[6] Lobo A F. The Industry 4.0 revolution and the future of Manufacturing Execution Systems (MES), Journal of Innovation Management, 3, 4, 2015, p. 16-21.

[7] Matsuda M., Sudo Y., Kimura F. A multi–agent based construction of the digital eco-factory for a printed-circuit assembly line, Procedia CIRP 41, 2016, p. 218-223

[8] Matsuda M., Matsumoto S., Noyama N., Sudo Y., Kimura F. E-catalogue library of machine for constructing virtual printed-circuit assembly lines, Procedia CIRP 49th Conference on Manufacturing Systems, Vol 57, 2016, p.562-567.

[9] Matsumoto S., Noyama N., Matsuda M. Construction of Virtual Printed-Circuit Assembly Lines Using an E-Catalogue Library of Machines, International Conference on Precision Engineering 2016.

[10] B. Kádár, A. Lengyel, L. Monostori, Y. Suginishi, A. Pfeiffer, Y. Nonaka, Enhanced control of complex production structures by tight coupling of the digital and the physical worlds, CIRP Annals - Manufacturing Technology, Volume 59, Issue 1, 2010, p. 437-440

[11] B. Kádár, W. Terkaj, M. Sacco, Semantic Virtual Factory supporting interoperable modelling and evaluation of production systems, CIRP Annals - Manufacturing Technology, Volume 62, Issue 1, 2013, p. 443-446

[12] W. Terkaj, T. Tolio, M. Urgo, A virtual factory approach for in situ simulation to support production and maintenance planning, CIRP Annals - Manufacturing Technology, Volume 64, Issue 1, 2015, p. 451-454