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Cyber-Physical System Simulation for Effective Coke Logistics

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Abstract

This paper proposes CPS(Cyber-Physical-System) simulation methodology for cokes logistics on ironmaking process. In a process where iron ore is melted to form molten iron, coke is used to melt iron ore. Coke has an important influence on the production of molten iron since it is the main material for the production of molten iron by burning iron ore in the furnace. Cokes for melting iron should be injected to a certain level or higher, due to the unpredictable state of the furnace. In ironmaking process, cokes is transported from oven to furnace through conveyor. The oven and furnace are designed to form a 1:1 supply line. In reality, however, a supply line of m:n is formed between the oven and the furnace because the production and consumption of furnaces and ovens may fluctuate depending on the process conditions. The determination of the coke route from oven to the furnace is an important issue because the large scale of the logistics line makes it difficult to change the route once determined. This paper proposes methodologies for CPS Simulation and examines the results of the simulations to help users make decisions about coke logistics.

Keywords: Coke logistics, CPS Simulation, Ironmaking, Supply line

INTRODUCTION

Steelmaking process consists of four major steps; 1) Ironmaking: iron ore is melted into molten iron, 2) Primary Steelmaking: impurities are removed from molten iron to make steel, 3) Continuous Casting: iron that is still in liquid state is injected into the mold to solidify, and 4) Primary Forming: apply a continuous force to stretch or thin the solidified iron.

The first step of the steelmaking (Ironmaking) requires two main raw materials, coke and iron ore. Coke is a fuel with few impurities and a high carbon content, and it is usually made from coal. Typically, coke made from coal are grey, hard, and porous. In this Ironmaking, the carbon monoxide released from the burning coke reacts with the iron ore to remove the oxygen while the heat melts the iron that remains. As shown in Figure 1, molten iron is produced and the reaction is

$$[Fe_2O_3 + 3\mathrm{C} \rightarrow 2\mathrm{Fe} + 3\mathrm{CO}]\ [Fe_2O_3 + 3\mathrm{CO} \rightarrow 2\mathrm{Fe} + 3CO_2].$$

Coke is the main fuel to melt iron ore in a furnace, and it affects to the product (molten iron) quality [1].

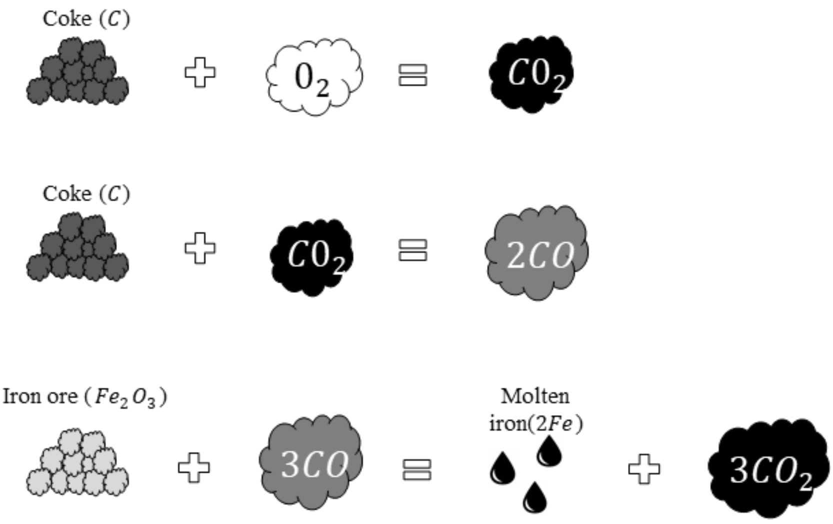

Figure 1. Reduction of iron ore with coke

Figure 2 shows a typical ironmaking process, and it consists of three steps; 1) cokes production from coal in multiple ovens; 2) supply cokes to furnaces according to demands; and 3) molten iron production from furnaces by melting iron ore with coke[2].

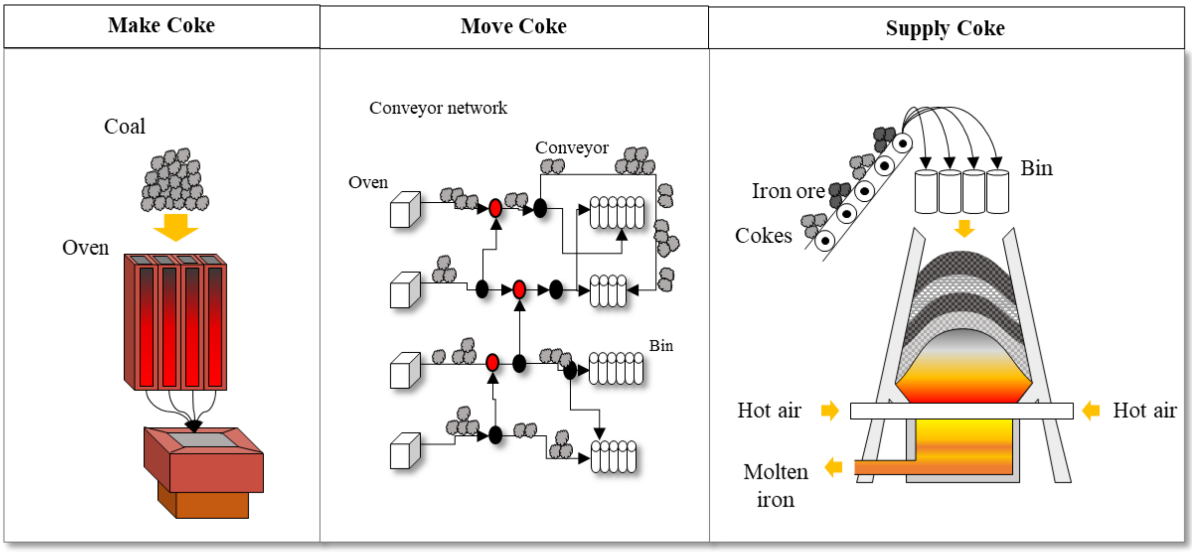

Figure 2. Three processes that coke is used in the ironmaking process

This paper is aimed at the second step, coke logistics. The Ironmaking process uses a conveyor to transport the coke produced in the oven to the furnace. In the actual process, the production of ovens and the consumption of furnaces vary depending on the circumstances. As a result, instead of forming a 1:1 supply line between the oven and the furnace, the network of m : n conveyors is formed as shown in Figure 3. A is an example of a layout to perform this study. The conveyor moves in one direction in the direction of the arrow. There is a connection between the conveyors, and while they are transported, the coke will merge with the coke from different ovens. The path correction between the conveyors is made through a device called the 'Damper' connecting the two. Damper moves the coke from one conveyor to multiple conveyors in a 1:n relationship. The coke is divided according to the ratio of the direction of the Damper. For example, if the size of the coke input to the Damper is equal to 1 when the Damper and the two conveyors are connected, the scale divided by the size of n and 1 to $1 - n$ $(1 \geq n \geq 0)$. The furnace has a store for storing coke before it enters the furnace. Since the consumption of coke in furnaces has a large variability, coke is stored in the 'Bin'(Storage) in advance [3].

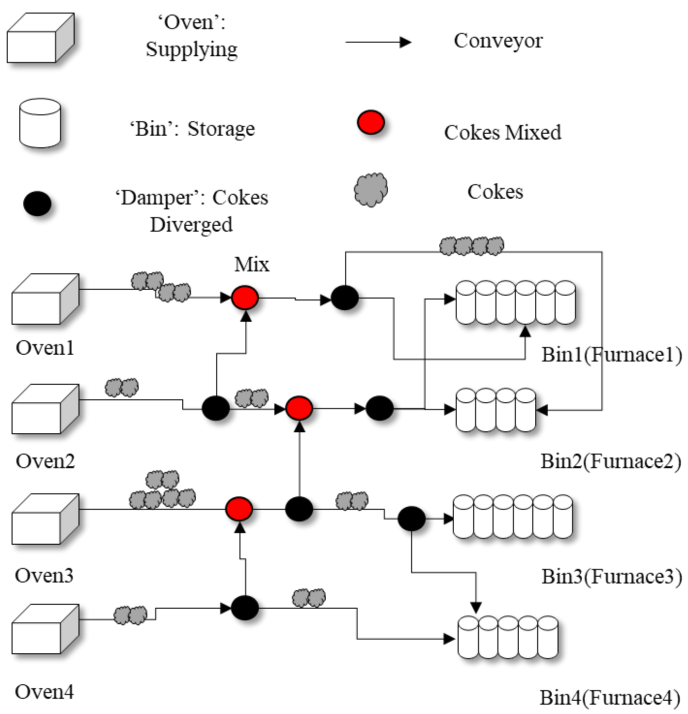

Figure 3. Ironmaking process layout design of logistics

Currently coke logistics are determined by operators using their know-how through CCTV screens as shown in Figure 4. However, the size of logistics layout grows with the connection of several furnaces and ovens. Depending on the size, the coke logistics is difficult for a person to visually identify and decide. Also, the movement time of coke from oven to furnace is long and once determined path is difficult to change.

Due to the high temperature inside the furnace and the structure in which the ore is stacked, it is currently impossible to identify the state of the furnace. The difficulty of predicting furnace conditions also makes it difficult to predict coke consumption at furnaces. Since it is not possible to predict the amount of coke consumed by the furnace, an adequate amount of coke must always be stored in the Bin [4] .

This paper presents real-time coke logistics simulations to assist operators in making decisions about the supply of coke. The results carried out provide information on the coke being injected into the Bin, which may help the operator maintain a certain coke in the bin.

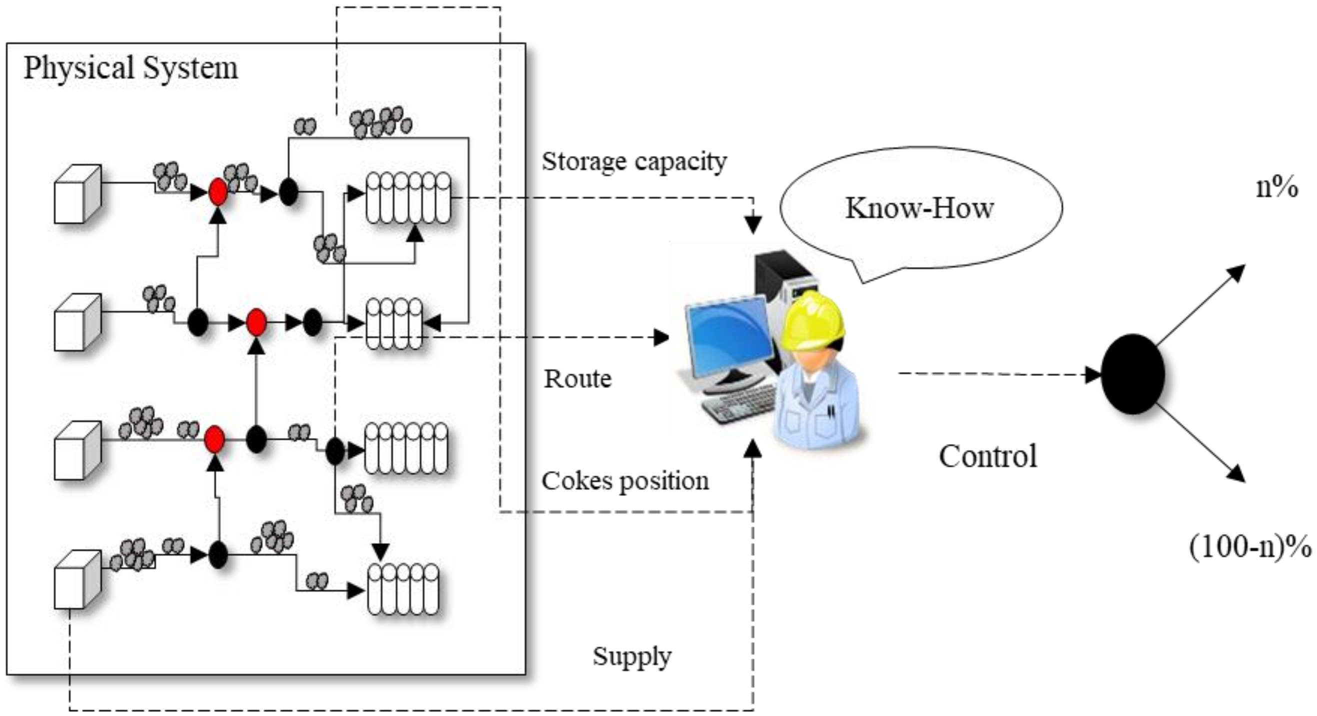

Figure 4. How to determine the path of coke route

CPS (Cyber-Physical Systems) is a system designed to interact between physical and computational components. The main purpose of this system is to enable real-time response using the computational logic and information of the physical systems at the site[5]. CPS, for instance , is applied in a small and large range of sizes, including Pacemaker, Unmanned Aerial Vehicle (UAV), and Power Grid[6]. The ironmaking process that is being considered in this study has a very large physical system, given the capacity of the coke and the length of the conveyor. As a result, existing workers were unable to identify the overall process situation and could make incorrect routing decisions. However, applying CPS Simulation to the ironmaking process models real-time information about the process's physical systems as a Cyber model, and Simulation can help workers before decision making.

CPS provides a method for responding to the dangers of information approaching in real time with the convergence of physical and logic systems[7]. In the ironmaking process, the operator had to visually observe the logistics movement of coke and respond to it using existing know-how. This would lead the operator to make a wrong judgement on the choice of coke route, taking into consideration the huge coke logistics line. There is a high risk since the wrong choice of coke paths can affect the quality of molten iron produced. However, CPS help the operator to make the correct decision by measuring the coke information present in the logistics line, such as Figure 5, and processing measured data.

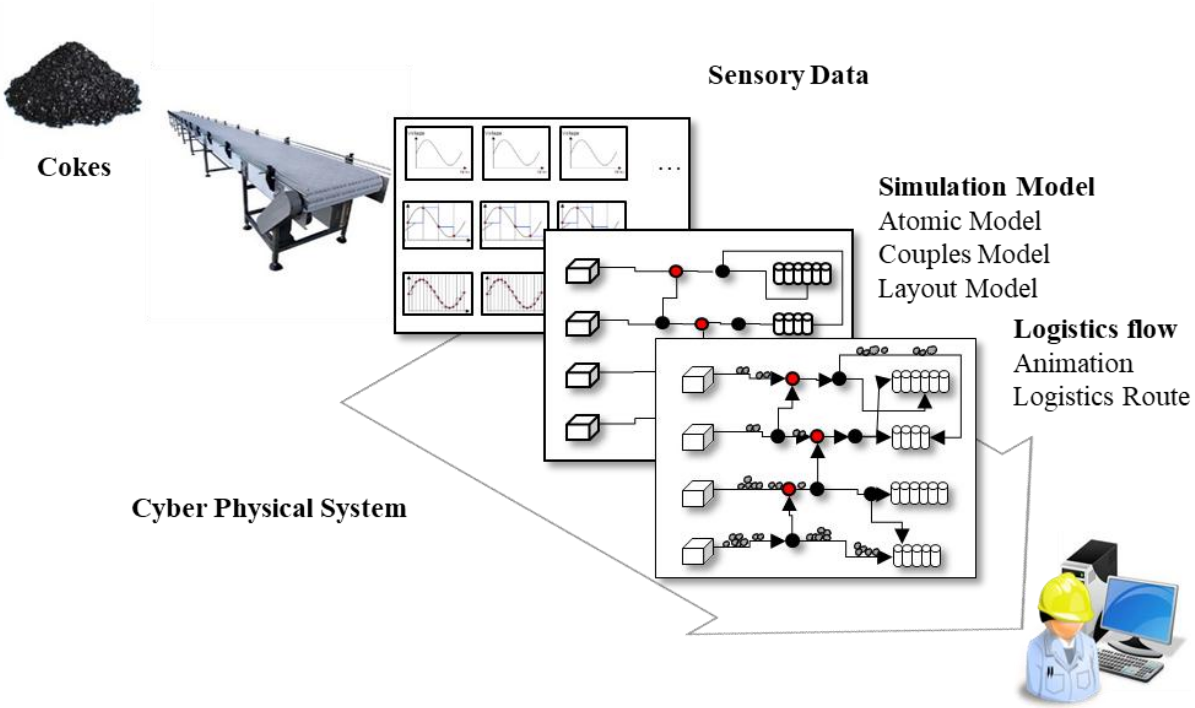

Figure 5. Visualization of logistics data through CPS simulation

Research at ironmaking, primary steelmaking, continuous casting, and primary forming is actively carried out to solve the problem of schedule and planning during the steel production process. Lixin suggested a method based on Just-in-time and NLP for scheduling the facilities in the performance process[8]. In addition, A&B proposes a scheduling model based on MIP to minimize the delay in delivery for arbitrary orders and delivery times during the primary steelmaking, continuous casting, and primary forming process[9]. Research at scheduling of ironmaking process proposes operating method to optimize the energy efficiency of the conveyor system[10]. However, since the energy efficiency of the conveyor system is the main objective, there are limitations to reflect the various constraints facing the actual steel production process. Therefore, this paper proposes an efficient reporting method to increase the operational efficiency of the facility while reducing the risk of variability.

CYBER-PHYSICAL SYSTEM ARCHITECTURE

Jay Lee at el design five-step architectures for the CPS (Cyber-Physical System). The architecture includes five steps, and as steps increase, the complex scope of data acquisition and utilization is extended using previous levels of techniques[11]. This paper purposes to applies CPS Simulation to coke logistics in the ironmaking process, and the five-step architecture is redefined for coke logistics as Figure 6. The first step represents the step to obtain information for real-time simulation. It is a step to obtain information to implement real-time Simulation. Real-time Simulation implementation requires real-time coke path and status information via sensing, and MES(Manufacturing Execution System) data for simulation modeling. In the second step, 'Conversion' is used to analyze the path of the coke using measured coke location information, and to determine the current state of the plant through the MES information. It serves to convert the data we obtain from ' Connection ' into the information we want through the conversion process. In the third step, 'Cyber' is a step to use the information gained to predict future situations. Simulations of future coke consumption and supply quantity are required for the simulation, and it is used to process and utilize the MES information from furnaces and ovens previously stored. In the fourth step, 'Cognition' is the process of using data created up to the third stage. Since this study aims to the efficiency of coke logistics, the routing and verification through Simulation belong to this level. In the fifth step, 'Configuration' means the stage in which decisions made in ' Cognition ' and the previous steps are applied directly to the physical system. Once applied to the 'Configuration', the system can perform all of the processes automatically without user intervention.

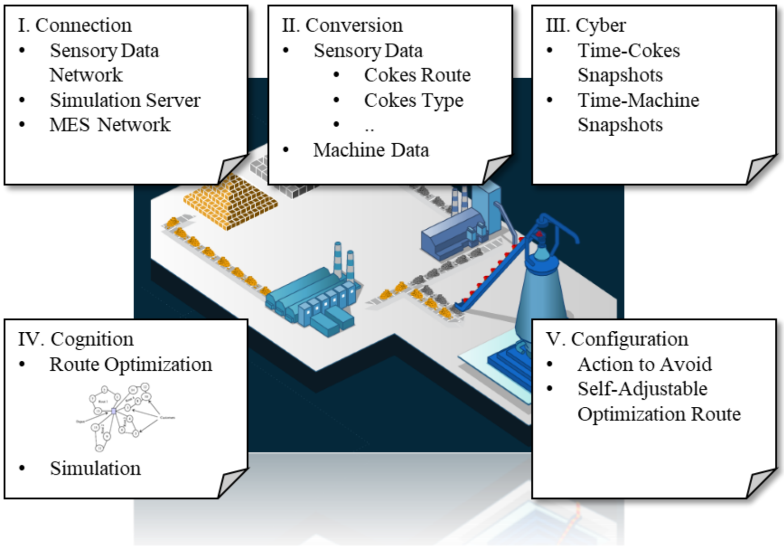

Figure 6. 5C architecture of Ironmaking CPS Simulation [2]

CPS SIMULATION METHODOLOGY

In order to implement CPS, convergence of fundamentally different technologies is essential. CPS has a number of Layers for convergence between different technologies. CPS Simulation requires individual layers of Physical, Software, and Communication [12]. This paper presents the use of three layers for CPS Simulation, as shown in Figure 7:

1. Physical Layer: The physical layer includes the initial state of the simulation model, such as MES data for creating simulation models such as Conveyor, Furnace, and the location of coke, as well as the collection of measurement data to create condition values. The acquired data generate models for real-time simulation.
2. Software-Layer: For the collected data, the process of processing data for simulation is Software Layer. The process uses the Layout Information to create a connection between the Simulation Models. Using the measured coke information, a relation between the data is generated, including current coke path information. Perform a simulation that meets your needs, through the information created.
3. Communication-Layer: The communication layer is responsible for connecting the physical and software layer. Data abstraction and server construction take place to converge each area. The server implements a Multi-User Connection environment for multiple users to connect to [Multi-User View Integration System (MUVIS): An Expert System for View Integration]. Simulation is performed using previously acquired and processed information, and result data corresponding to KPI (Key Performance Indicator) is provided to users.

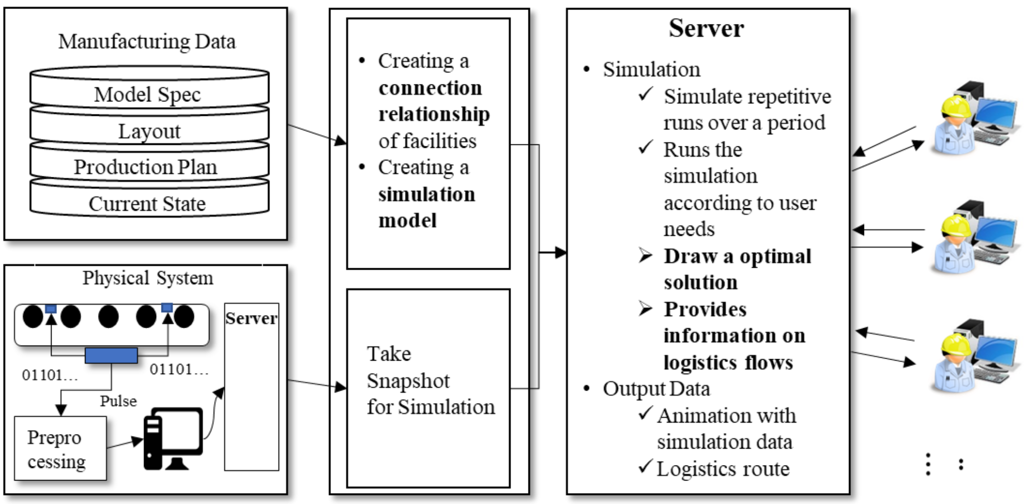

Figure 7. CPS simulation methodology about Ironmaking process

Real-time simulation requires that the simulation can be performed with variable data. Simulation is performed by generating a simulation model from each data input through the MES. For the creation of a simulation model, the MES data is abstract with the corresponding information.

Simulation with example models presented in this paper has the same data table as Figure 8. Since the abstraction of the data presented in this paper is information about examples, the data are limited and small. The data are classified into tables according to the characteristics of each information.

- Equipment spec table: It is the reference information for the equipment. It has an ID and type identifying the equipment and other information indicating the characteristics of the equipment.
- plan and an example survey to consume coke.
- Layout table: It forms the connection between the equipment. The "From", "To" equipment information is used to create the direction in which coke flows and to create a logical layout of the model when performing the simulation.
- Route schedule table: It determines the schedule for dividing the coke from one conveyor to multiple conveyors. Since the conveyor has only one direction of movement, the movement of dividing coke through Damper becomes the determining element of path coke.
- Supply/Consume schedule table: It shows schedule information on the amount of coke in the oven and the consumption of the coke in the furnace. Simulation is carried out by bringing in an existing

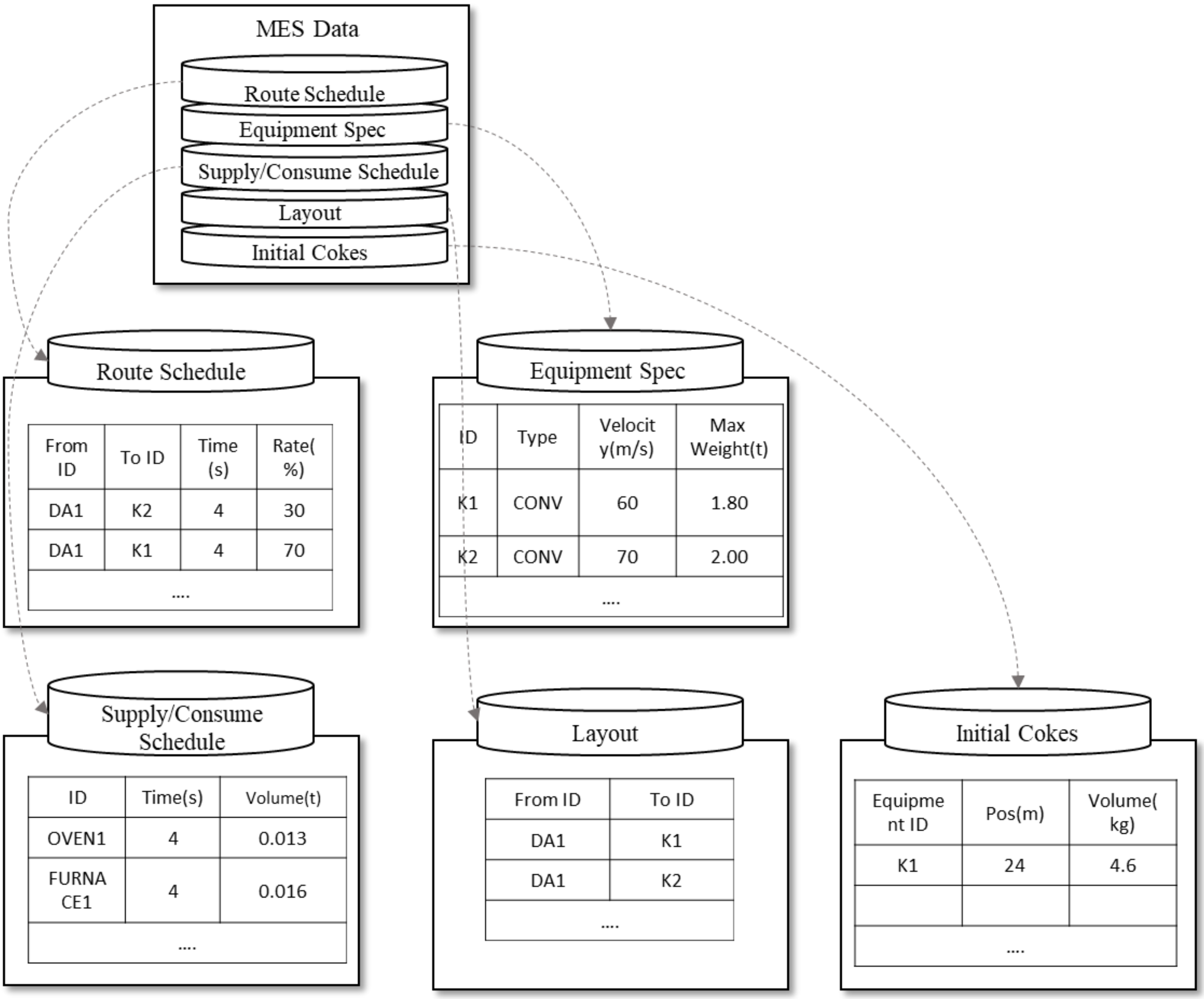

Figure 8. Data about ironmaking process

Abstract information shapes a simulation model. Using the aforementioned data table, it forms a model for each. The information corresponding to the actual physical model changes with the context of the process. Failure to produce the correct abstraction and model according to changing information significantly reduces the ability to receive and utilize real-time information. Therefore, creating a simulation model based on changing information is an essential component of CPS Simulation [13].

The information that is abstract from the MES data forms the simulation model as shown in Figure 9. Each equipment information and coke information forms the layout of the ironmaking process, and schedule information provides a basis for future data for simulation performance.

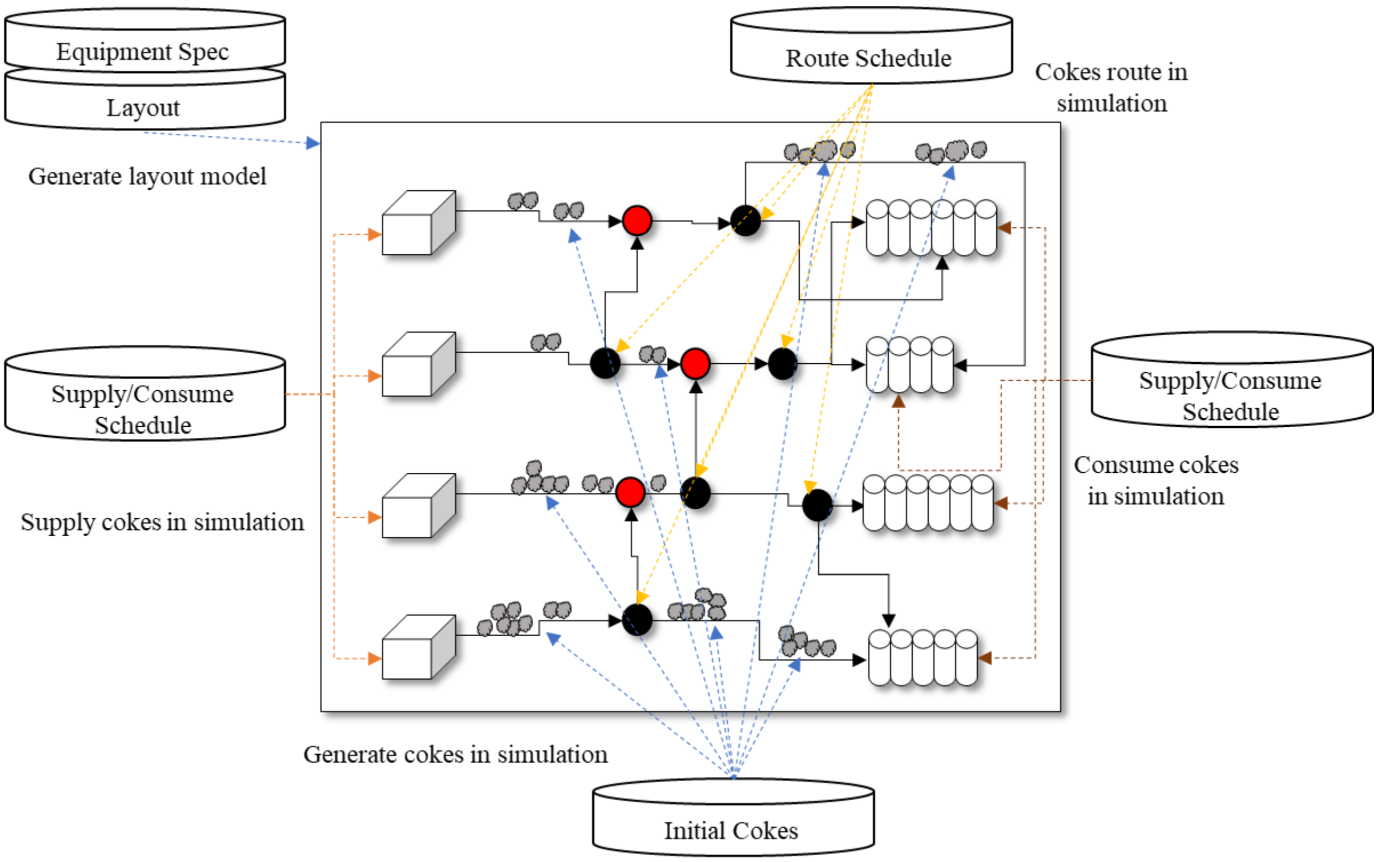

Figure 9. Simulation model formation using MES information

SIMULATION RESULTS

Simulation is conducted through a real-time simulation model that is based on real-time coke information and MES data obtained from physical systems. Simulation should be fast to help users make decisions, and the resulting data should be able to show results that match the Animation or KPI.

Coke logistics is a continuous event, not a discrete event. There are difficulties in providing the type of coke depending on the oven and the process of animation due to continuous coke movement. Therefore, Simulation Engine is modelled for discrete by blocking the continuous coke motion at the speed of Conveyor. Accordingly, it makes use of DEVS Formalism.

Figure 10 is the resulting data from the simulations performed through Layout model Figure 3. The horizontal axis means time (minutes), the vertical axis means the ratio of the storage of coke storage to the furnace intended for storage of ‘Bin 1’ of ‘Furnace 1’ A red dotted line means the essential storage quantity of coke that should be stored in the store and if it falls below about 70 %, it means the coke injection plan is incorrect.

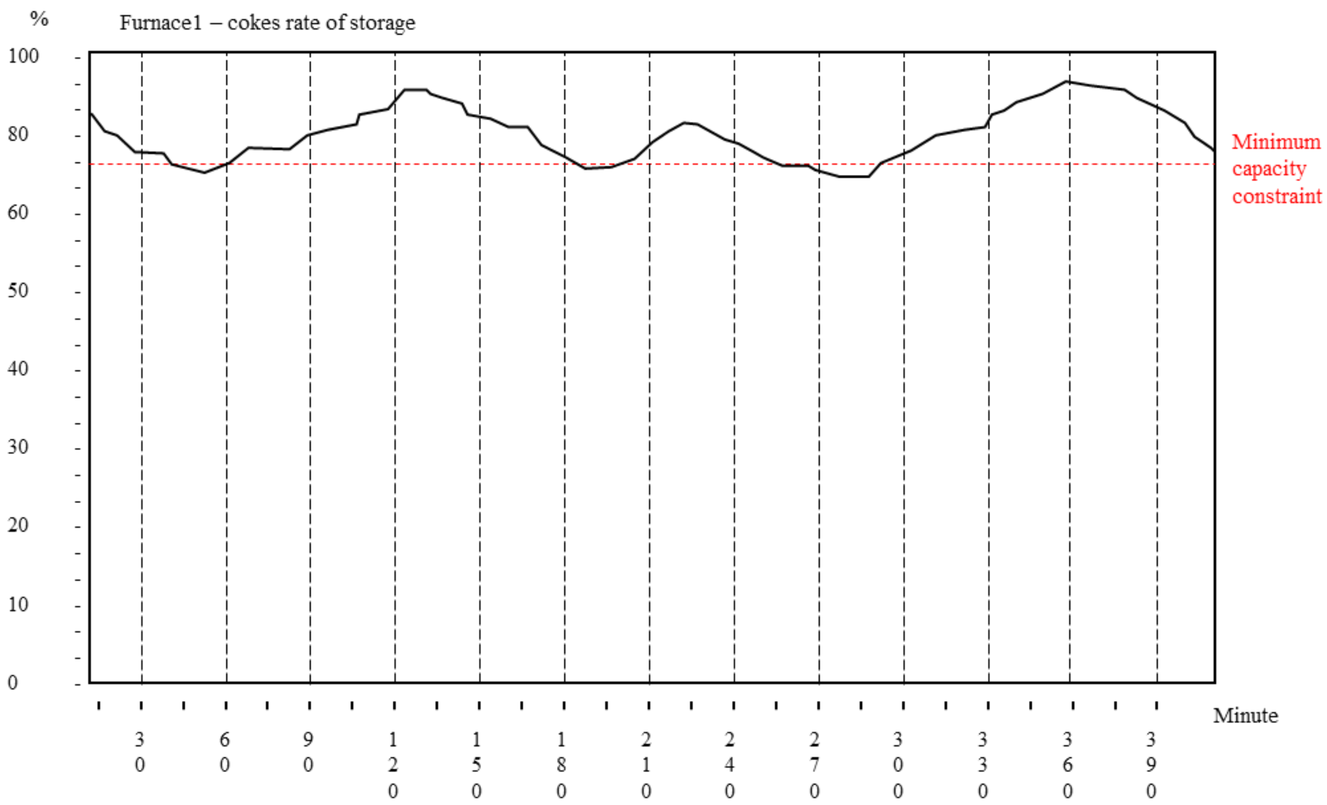

Figure 10. Result of Simulation

SUMMARY

Because it is not easy to obtain real-time data for the ironmaking process, it is difficult to introduce the automated process. With the development of sensor technology, this paper presented a methodology for performing real-time simulations of coke logistics in the ironmaking process. The quality and routing of coke is very important because the problems caused by the coke being put into the furnace cause a lot of damage. Therefore, in situations where decisions must be made in real time, simulation is a safety device that makes the wrong decision avoided, and further it may be a way to automate coke routing.

The CPS Simulation Methodology were presented in this paper. Using the data provided by the physical system, we created a simulation model and presented a methodology that could be used by many users. The results produced are based on information that is predicted at the start of the simulation. Information at the start and its predictions may have a significant impact on the simulation results. However, it is not possible to model the internal state of the furnace because the inside of the furnace consists of an unmeasurable high temperature. The amount of coke injection can be predicted according to the coke plan to be injected from the oven, but the consumption of coke is not accurately foreseeable. This impossibility is a problem that must be addressed in the future with the development of sensor technology and the study of furnaces.

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