A Steel Tube Production Planning and Scheduling with Product-Dependent Changeover Time Using Digital Twin

Chayaporn Maitreesorasunte[1], Chawalit Jeenanunta[2], Jirachai Buddhakulsomsiri[3], Rujira Chaysiri[4], Warut Pannakkong[5], Jessada Karnjana[6] and Masahiro Nakamura[7]

[1,2,3,4,5]Sirindhorn International Institute of Technology, Thammasat University, Pathumthani, Thailand
[6]National Electronics and Computer Technology Center,
National Science and Technology Development Agency, Pathumthani, Thailand
[7]Osaka University, Osaka, Japan
E-mail: chayap.mai@gmail.com, chawalit@siit.tu.ac.th, jirachai@siit.tu.ac.th, rchaysiri@siit.tu.ac.th, warut@siit.tu.ac.th, jessada.karnjana@nectec.or.th and nack@lexer.co.jp

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***Abstract*—Steel tube manufacturing industry is one of heavy industry that use a lot of labor, large and heavy machineries, intense capital, and high technologies. The production planning and scheduling of steel tube manufacturing is complicated because of a long tool setup time and machine conditions. Moreover, there are half-thousands of different finished goods. In order to produce efficiently and maximize machine utilization, this paper proposes a digital twin of steel tube production process focus on forming process. The digital twin could be used for planning and scheduling to manage complexity of machinery setup, priorities production, fulfil inventory without shortage and to conduct what-if analysis and compares for the scenarios of different schedules. The digital twin provides production model simulating precise production total time, tool setup time, number of products and production deadline. The simulation model is tested with forty-nine products on three identical machines with their tool setup time. It reduces the production planning time of the planning engineer and provides accurate schedule of each product.**

***Index Terms*—Production Planning and Scheduling, Digital Twin, Steel Tube Manufacturing**

I. Introduction

"Digital twin" is defined as virtual simulation of physical with real environment by advance of technology such as paradigm of air force vehicles [1]. The digital twin concept is used for predicting, evaluating and analyzing the physical change by technologies [2]. In manufacturing industry, the digital twin is known as one of the industries challenging to become industry 4.0 or smart manufacturing [3]. Digital twin for manufacturing has been explicated to drive and achieve smart manufacturing [4]. Digital twin disguises shop-floor of real factories with real facility, equipment and environment before implementing [5] and applied the real factories digital twin with the new information technologies of industry 4.0 [6]. For production planning, digital twin is applied as decision support system aiming on tracking material flow and operation systems [7]. The important objective of digital twin on manufacturing is to reduce cost and accrue efficiency [8].

In steel industry, digital twin is applicable from products to services [9]. One of possible applicable area is production planning and scheduling. An optimization and a simulation are applied on steel sheet and coil production scheduling [10]. In addition, they utilize on buffers and inventories management of steel sheet production to analyze and improve the system [11]. For steel tube production, Mixed Integer Programing (MIP) is utilized for optimizing the job sequences considering on machine capability and minimum makespan [12]. On the other hand, sequence-dependent setup time scheduling problem for steel tube production is discussed and solved by heuristics algorithm [13]. In this paper, we purpose to utilize the digital twin to help improving the production planning and scheduling.

II. The Steel Tube Manufacturing Process

There are two production processes in a steel tube manufacturing process: slitting process and forming process as shown in Fig. 1 and Fig. 2. Slitting process cuts a metal sheet roll to be metal films with the specified width. The forming process takes the steel film to form tube. This paper considers forming process because of the complexity of tool setup with three machines and forty-nine of various products.

There are three types of finished products: round pipe, square pipe and rectangular pipe. In each machine, there are different tool setup time. There are twelve tools to be changed and these tools can be changed all or some of them. The products are grouped by shape or type, then they are grouped by outside dimension (OD). It takes thirty to forty minutes setup time for changing between product within the same OD group. Furthermore, different OD groups are grouped by tool group. The tool setup time in the same tool group is around one and half to eight hours and the setup time of tool changing between tool group is three to eleven hours depend on machine conditions and number of tools changed.

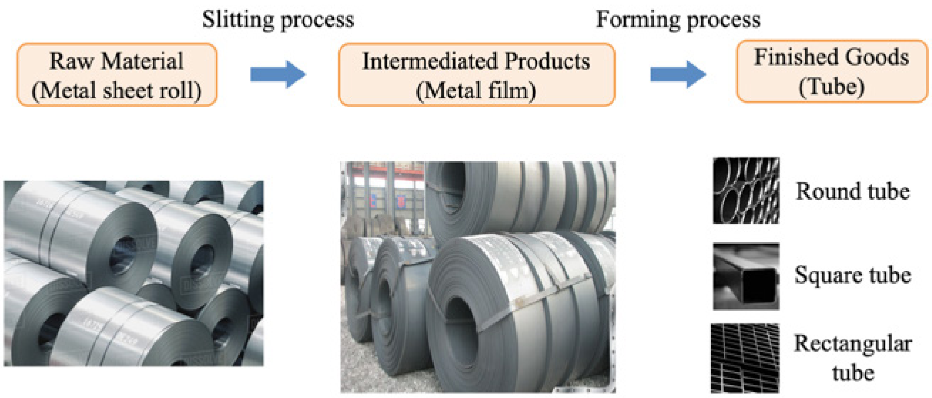

Fig.1. Steel tube production process

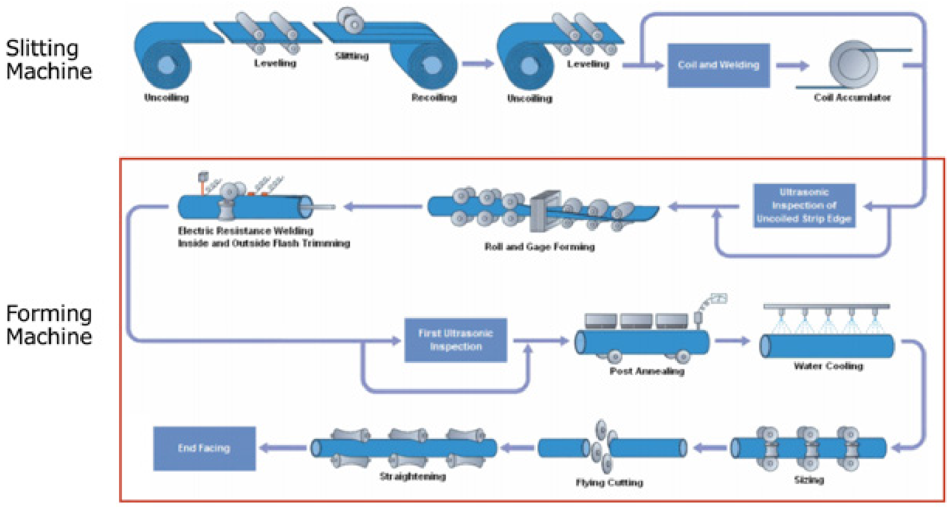

Fig. 2. Steel tube production process

III. Digital Twin of Forming Process

This section, we explain how to construct the digital twin of the steel tube manufacturing. The test data are from the actual case that there are ten forming machines with around half-thousand products. There are three identical forming machines with forty-nine products that would require the optimal scheduling that maximize machine utilization. Therefore, the heuristic method is applied to find the nearest optimal solution and the digital twin is created to represent these three identical forming machines to help identifying tool setup using the Software-as-a-Service (SaaS) on cloud, called GD.findi.

GD.findi requires the data model consist of the "floor plan" and "process plan". The floor plan specifies the factory layout including the station or machine locations and size as shown in Fig. 3. The process plan specifies the production process of each product group and each include the work time and the associated stations. Moreover, process requires the input parts and the output parts with their quantities. The production process represents each OD group where the forming process time are the same. Fig. 4 shows the example of production process that represents one of the OD groups. The detail process properties are shown in Table II.

The tool setup condition on the forming machines depends on the sequence of product. The digital twin of steel tube forming production process is created to represent the tool set up that depends on the sequence of product, the OD group and the tool group. The tool setup time can be specified once there is a change between different OD group or different production process. Table I shows the tool setup time for forty-nine products in eight OD groups and three tool groups.

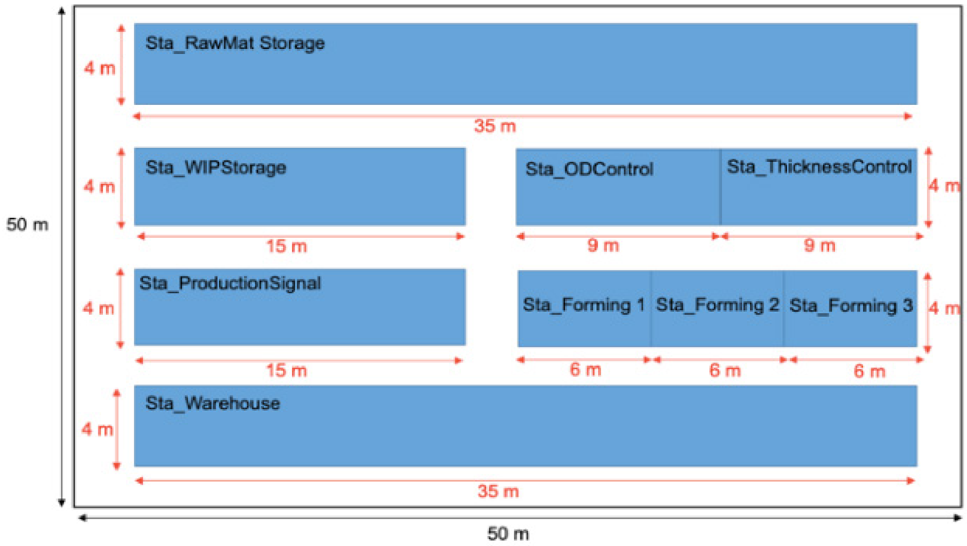

Fig. 3. Floor plan for GD.findi simulator

The Proc_ODControl and the Pro Thickness Control are created as dummy processes for tool changeover setup. The Proc_ODControl is for setting up the tool once there is a change between OD group. The Proc_ThicknessControl is for setting up the tool once there is a change in product and it takes thirty minutes setup time. If the next product is in the same OD group, Proc_ODControl setup time is 0 because it uses the same OD tool and the Proc_ThicknessControl setups the thickness tool. If there is a change of product between OD group, both Proc_ODControl and Proc_ThicknessControl will set the tool but the setup time of the Proc_ODControl covers the setup time of the Proc_ThicknessControl.

Furthermore, there is a dummy process, Proc_Signal, which is to wait for the Proc_Forming processe finished the work and send production signal to Proc WIPStorage to start its process.

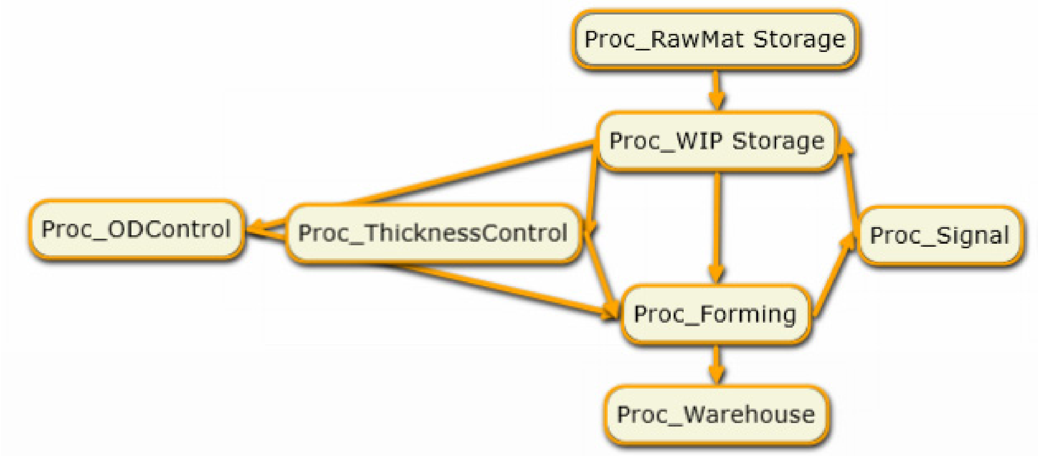

Fig. 4. Production process for one of the OD group

TABLE 1
THE TOOL SETUP TIME BETWEEN OD GROUP AND TOOL GROUP

			Tool group 1			Tool group 2		Tool group 3		
			OD group 1	OD group 2	OD group 3	OD group 4	OD group 5	OD group 6	OD group 7	OD group 8
		Thickness (mm.)	1.2-3.5	1.2-3.5	1.2-3.5	1.2-3.5	1.2-3.5	1.2-3.5	1.2-3.5	1.2-3.5
Tool group 1	OD group 1	1.2-3.5	30 mins	4	4	5	5	6	6	6
	OD group 2	1.2-3.5	4	30 mins	3	5	5	6	6	6
	OD group 3	1.2-3.5	4	3	30 mins	5	5	6	6	6
Tool group 2	OD group 4	1.2-3.5	5	5	5	30 mins	3	6	6	6
	OD group 5	1.2-3.5	5	5	5	3	30 mins	6	6	6
Tool group 3	OD group 6	1.2-3.5	6	6	6	6	6	30 mins	4	4
	OD group 7	1.2-3.5	6	6	6	6	6	4	30 mins	3
	OD group 8	1.2-3.5	6	6	6	6	6	4	3	30 mins
Number of products			5	6	6	7	7	9	3	6

TABLE II
PRODUCTION PROCESS SETTING

Any Production Process	Proc_RawMat Storage	Proc_WIP Storage	Proc_OD Control	Proc_Thickness Control	Proc_Signal	Proc_Forming	Proc_ Warehouse
Work time [s]	60	120	0	0	0	3600	60
Set up Time [s]	0	0	0	0	0	0	0
Frequency [N:Time] [s]	-	-	-	-	-	-	-
Input from Local In [ID/Name/ Quantity]	[RM/Raw Material/1]	-	-	-	-	-	-
Input from Previous Process [ID/Name/ Quantity]	-	[RM/ Raw material/1] [ProductionSignal/ ProductionSignal/1]	[ODSignal/ ODSignal/1]	[ThicknessSignal/ ThicknessSignal/1]	[ProductionSignal/ ProductionSignal/1]	[ODSignal/ ODSignal/1] [ThickSignal/ ThickSignal/1] [IP/Intermediate Product/1]	[FG/Finish Goods/10]
Output to Local Out [ID/Name/ Quantity]	-	-	-	-	-	-	[-/-/10]
Output to Next Process [ID/Name/ Quantity]	[RM/Raw Material/1]	[IP/IP/1] [ODSignal/ ODSignal/1] [ThickSignal/ ThickSignal/1]	[ODSignal/ ODSignal/1]	[ThicknessSignal/ ThicknessSignal/1]	[ProductionSignal/ ProductionSignal/1]	[ProductionSignal/ ProductionSignal/1] [FG/ Finish Goods/400]	-
Associated Station	Sta_RawMat Storage	Sta_WIP Storage	Sta_ODControl	Sta_Thickness Control	Sta_Production Signal	Sta_Forming1, Sta_Forming2, Sta_Forming3	Sta_Warehouse

IV. HEURISTIC FOR PRODUCTION PLANNING AND SCHEDULING PROCESS

This section explains a heuristics method for production planning and production scheduling with objectives to maximize the Overall Equipment Effectiveness (OEE) or minimize the tool setup time.

The heuristics algorithm find the best production schedule and the detailed production operation is simulated in the digital twin model based on the given schedule to obtain the detailed operations and its KPIs. The steps of heuristics is used scheduling is contained as follow.

Step 0: For each station does follow the step.

Step 1: Getting the previous 2-month production sequence $S = \{P_1, P_2, \ldots, P_m\}$ of each machine.

Step 2: Identify the last product P' produced in last month. Then identify product P' in the production sequence S and continue the sequence from a product after P'.

Step 3: For each product P_i in sequence S, compute the production quantity, production start date and time, production finishing date and time, and production lead time. The production of P_i can start after the previous production finish and the tool is completely setup.

Step 4: If the production of P_i cannot produce before P_i is out of stock, swap the sequence of P_i with the product that come before P_i in the sequence S base on the following priority.

- Swapping product P_i with the product that come before P_i within the same OD group.
- Swapping the whole OD group that contains product P_i with the other OD group that come before but within the same tool group.
- Swapping the tool group that contain product P_i with the other tool group that come before.

Step 5: Recalculate production quantity, production start date and time, production finishing date and time, and production lead time of all of products that swap the position in the sequence.

Step 6: Repeating from step 3 until all products can be produced before they are out of stock.

After getting production schedule from the heuristic step, the production schedule are assigned in digital twin model that was created in GD.findi as shown in Fig. 5. The digital twin model with the production schedule is simulated and return the KPIs to check quality of the schedule. The KPIs include OEE, utilization efficiency, machine capability, process capability, and production ratio.

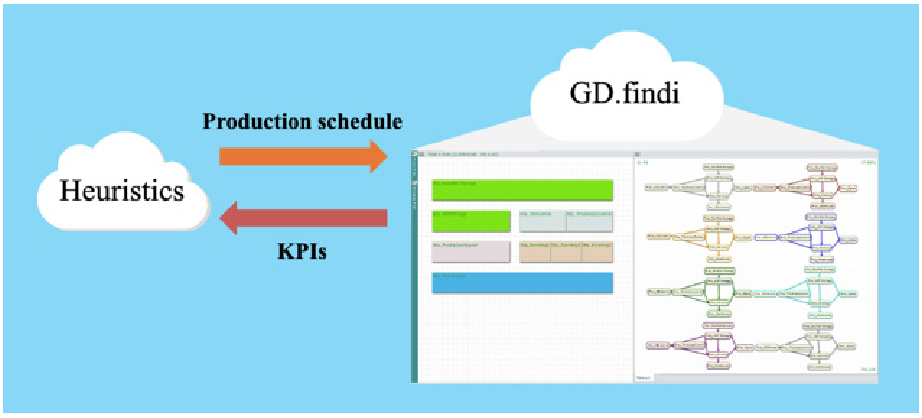

Fig. 5. Heuristics and GD.findi information transfered

V. Results

Once the digital twin of the steel tube production is created, various production schedules are tested with forty-nine products of eight OD groups and three tool groups. The production quantity are 500 kilograms for each product. The computational time for the heuristic and simulation takes about 2 minutes per each schedule. The manual scheduling takes around one to two days. Moreover, the planner could conduct what-if analysis to compare between various schedules and scenarios within the reasonable time. The comparing of computation is shown in Table III. The best schedule is when the sequence is arranged by grouping the product in the same OD group. Then the products with the same tool group are arranged in sequence. The example of the nearest optimal sequence is shown in Fig. 6. This optimal sequence provides the highest OEE. The nearest optimal result of the tested data using the digital twin is shown in Fig. 7.

TABLE III
COMPARING AVERAGE COMPUTATION TIME

Data	Average computing time (minutes)	
	Manual	Heuristics and digital twin
Test case	720	2.06

VI. Conclusion

The steel tube manufacturing has long tool setup time and long production time with expensive machine. Their tool setup time and machine conditions for the forming process are complex. The production planning and scheduling of the forming process for around five-hundred different products could take two to three days to do it manually. Consequently, the digital twin of the forming process for the steel tube production is proposed for production planning and scheduling to improve making decision. This steel tube production digital twin is evaluated with the example of forty-nine products, eight OD groups and three

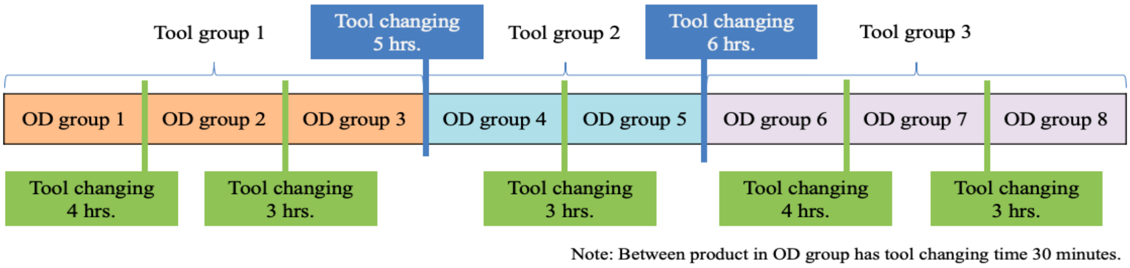

Fig. 6. The example of the nearest optimal production sequence with tool setup time

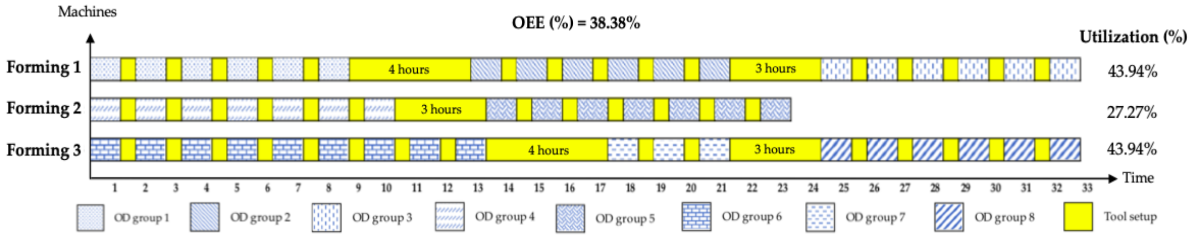

Fig. 7. The optimal Steel tube production scheduling with tool setup time

tool groups. The heuristic for production planning and scheduling is applied to find the nearest optimal production sequence. The results of digital twin show the exact schedule with number of products, total production time, tool setup time and production start and end time. This tool helps the planner to make the decision with less planning and scheduling time than planning manually. Furthermore, it serves to manage machinery and tool setup, prioritize the production and satisfy inventory level. For future research, the improvement of heuristics for production scheduling should be explore and utilize this digital twin. Moreover, the Artificial Intelligent (AI) techniques should be explore to improve quality of schedule.

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Chayaporn Maitreesorasunte is a Ph.D. student and research assistant in School of Management Technology at Sirindhorn International Institute of Technology (SIIT), Thammasat University, Thailand. She received the B.Sc. in Management Mathematics, Faculty of Science and Technology and M.Sc. in Management Mathematics, Sirindhorn International Institute of Technology (SIIT), Thammasat University, Thailand. Her research interests are Operation research, Logistics and supply chain management and Production simulation.

Chawalit Jeenanunta is an associate professor of School of Management Technology (MT), Sirindhorn International Institute of Technology, Thammasat University, Thailand. He received the B.Sc. in Mathematics and B.Sc. in Computer Science, and M. Sc. in Management Science from University of Maryland and he received his Ph.D. in Industrial and Systems Engineering from Virginia Polytechnic Institute and State University. His Research interests are in area of applications of operations research, simulation, large-scaled optimization and supply chain management.

Jirachai Buddhakulsomsiri is an associate professor in School of Manufacturing Systems and Mechanical Engineering, Sirindhorn International Institute of Technology, Thammasat University, Thailand. He received the B.Eng. in chemical engineering, Chulalongkorn university, Thailand and M.Sc. in industrial engineering, M.Sc. in statistics, and Ph.D. in industrial engineering from Oregon State University, USA. His research areas are Applied operations research, Data mining, Production planning and control, Systems simulation, Engineering economics analysis, and Logistics & supply chain management.

Rujira Chaysiri is a lecturer at the School of Management Technology at the Sirindhorn International Institute of Technology, Thammasat University, Thailand. He received a B.A. in Mathematics from the University of Virginia, M.Sc. in Operations Research from Columbia University, and Ph.D. in Systems Engineering from the University of Virginia.

Warut Pannakkong is a lecturer in School of Manufacturing Systems and Mechanical Engineering, Sirindhorn International Institute of Technology, Thammasat University, Thailand. He received the B.Eng. in Industrial Engineering and M.Eng. in Logistics and Sypply Chain Systems Engineering, Sirindhorn International Institute of Technology (SIIT), Thammasat University, Thailand and Ph.D. in Knowledge Science, Japan Advanced Institute of Science and Technology, Japan. His research areas are Time series forecasting, Data mining, Logistics and supply chain management, Discrete-event systems simulation, Agro-industry management, and Vehicle routing and scheduling.

Jessada Karnjana is a researcher in Embedded System Technology Laboratory Advanced Automation and Electronics Research Unit, National Electronics and Computer Technology Center, National Science and Technology Development Agency, Thailand. He received the B.Eng in Electronics Engineering at King Mongkut's Institute of Technology Ladkrabang, Thailand, M.Eng. in Microelectronics from Asian Institute of Technology, Thailand, Ph.D. in Engineering and Technology, Sirindhorn International Institute of Technology, Thammasat University, Thailand and Ph.D. in Information Science, Japan Advanced Institute of Science and Technology, Japan Asian Institute of Technology, Thailand.

Masahiro Nakamura is a C. E. O. of Lexer Research Inc who develop the simulation cloud computing "GD.findi". He received the Ph.D. in Production Science, Osaka University, Japan.