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Operation Scheduling for Yarn Production with The Autonomous Distributed Manufacturing Systems (ADiMS) Concept

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Abstract--*The textile industry is one of the Indonesian priority industries for the Industry 4.0 development program. There are a lot of textile industries still in the Industry 2.0 phase. These industries need to adopt Industry 4.0 concepts without automating the production operation to compete with their rivals. The digital twin and Autonomous Distributed Manufacturing Systems (ADiMS) concept were used to implement Industry 4.0 in this case. The objective of this research is to develop an operation scheduling system that can distribute the yarn manufacturing scheduling task to each workstation in a virtual production system using the ADiMS concept. Every actual manufacturing component in ADiMS is simulated in a virtual production system to interact with one another and make decisions; then a process-based product model is developed to capture all the conditions from yarn production in real production systems. Each production element is modeled as an object in Python programming. The simulation is set up to have 31 machines that are ready to be used for production scheduling and 2 types of products. The operation scheduling system with the Autonomous Distributed Manufacturing Systems (ADiMS) concept for yarn production has been created and simulated in a virtual environment and shown the operation schedule that fits the desired criteria.*

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1. INTRODUCTION

One of the Indonesian priority industries for the industry 4.0 development roadmap is the textile industry. This is due to the fact that the textile industry contributes significantly to the employment of both skilled and unskilled labor [1]. In general, local industries in Indonesia are still in the industry 2.0 phase, which still uses manual labor to conduct production activities and to manage the shop floor, and this includes the textile industry. The main products of the textile industry are yarn, fabric, and finished goods [2]. Yarn manufacturing, or the spinning process, is one of the textile industry's ways to generate yarn in cones as the final result. Depending on the type of yarn being produced, there are several steps involved in the manufacturing process, but in general, blowing, carding, drawing breaker, drawing finisher, roving, ring spinning, and winding machines will all be used in the process.

To compete with other companies, industries that are still at the industry 2.0 level need to upgrade themselves to a higher level by adopting Industry 4.0 concepts without automating the primary production operation [3]. Digital twin is one of the primary tools to implement the industry 4.0 concept by digitalizing, optimizing, and managing the factories in a more intelligent and efficient way [4]. In general, the digital twin is defined as virtual representations of physical items throughout their lifecycle that can be comprehended, studied, and reasoned with real-time data [5], [6]. Digital twins can be characterized into three components as follows: a physical entity, a virtual mirror replica of the physical model, and the interaction and exchange of data between the two objects [7]. In manufacturing, digital twin capabilities can be applied to provide reliable, effective, and efficient processes.

The other concept to implement Industry 4.0 is the Autonomous Distributed Manufacturing Systems (ADiMS) concept. Each component of actual production is represented in a virtual production system; ADiMS inherits the digital twin concept. Tasks are assigned to each virtual production component, and each virtual production component has the capacity to interact with other components and make decisions [8]. By assigning these tasks, the production schedule can always be modified to accommodate the maintenance schedule, each production element can schedule itself, and maintenance schedules can be scheduled automatically [9].

Previous research has discussed production scheduling. Reference [10], [11] uses a simulation-based scheduler and presents the Dynamic Scheduling (DS) framework to maximize production. Reference [12] suggests using digital twins in offsite construction for scheduling, production estimation, and real-time monitoring by integrating computer vision, ultrasonic sensors, machine learning-based prediction models, and 3D simulation. Reference [13] outlines a process for using genetic algorithms to schedule a textile production line in the most efficient way possible. The references mentioned before are trying to schedule production, but the scheduler is not integrated with the production system, especially yarn production. The ADiMS concept, as one of the production system concepts, will be suitable for use for scheduling yarn production. Based on this matter, the objective of this research is to develop an operation scheduling system that can distribute the scheduling task to each workstation in a virtual production system and schedule yarn manufacturing operations using the ADiMS concept.

2. METHODOLOGY

The topic of Industry 4.0 and Digital Twin (DT) discussion is not separable. Digital Twin (DT) tries to automate and digitize production processes with the goal of creating more effective workflows [14]. The products output from the machines and production machines (which are blowing, carding, drawing breaker, drawing finisher, roving, ring spinning, and winding machines) are the production elements from yarn production that will be digitized into the virtual world. These virtual production elements have the ability to recognize the possible production processes they can work on and the production processes that they cannot. These virtual production elements are also capable of determining the production schedule that is implemented on the element and whether there is a blank schedule for production. The technique involves integrating machine data, process data, and operation schedule data to production element model data in a relational database (RDB).

To facilitate the operation scheduling process, the concept of Autonomous Distributed Manufacturing Systems (ADiMS) is applied in the virtual production element. Every actual manufacturing component in ADiMS is simulated in a virtual production system. It allows for these virtual production element models to interact with one another and make decisions regarding how to handle production management issues. The manufacturing system will remain adaptable in the presence of unexpected events or disruptions due to the autonomous nature of its individual components[15]:

Product models are used as a system integrator to represent product information for the production elements of the product. For the duration of its life cycle, this product model will retain all the information from the actual product. Every modification made to the actual product will serve as a catalyst for updating the product model's information. A structure model is used to model the product in the virtual world. A structure model is a model that illustrates how a component of a final product is put together [16].

The structure model-based product model represents all product components as nodes, and each node has a relation to each other based on the relationship in how the components are assembled. As an exampleThe structure model-based product model for the scheme described above is shown in **Figure 1**. Because yarn isn't made up of different components but rather from a big ball of fiber that is processed in several steps to make many cones of yarn, the structure-based product model won't work for the yarn product in the Autonomous Distributed Manufacturing Systems (ADiMS) idea. A new product model will be proposed to be used in the Autonomous Distributed Manufacturing Systems (ADiMS) for yarn production.

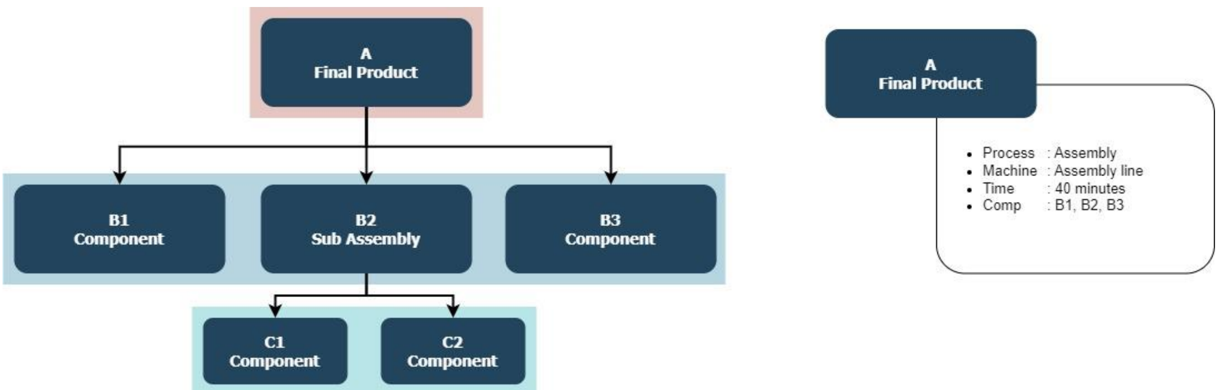

Figure 1. The structure model-based product model

Instead of using product structure to model the yarn product in a virtual production system, a process-based product model is developed to capture all the conditions from yarn production in real production systems to be used in virtual production systems. In the process-based product model, each subassembly and component will not be broken down into nodes, but the process to make the yarn will be broken down into nodes. Yarn production processes consist of blowing, carding, drawing breaker, drawing finisher, roving, ring spinning, and winding. Each process is made into nodes; this node will be used to represent the actual condition of the yarn production. The process model-based product model for the scheme described above is shown in **Figure 2**. These process models then will act as production elements that can make decisions based on the Autonomous Distributed Manufacturing Systems (ADiMS).

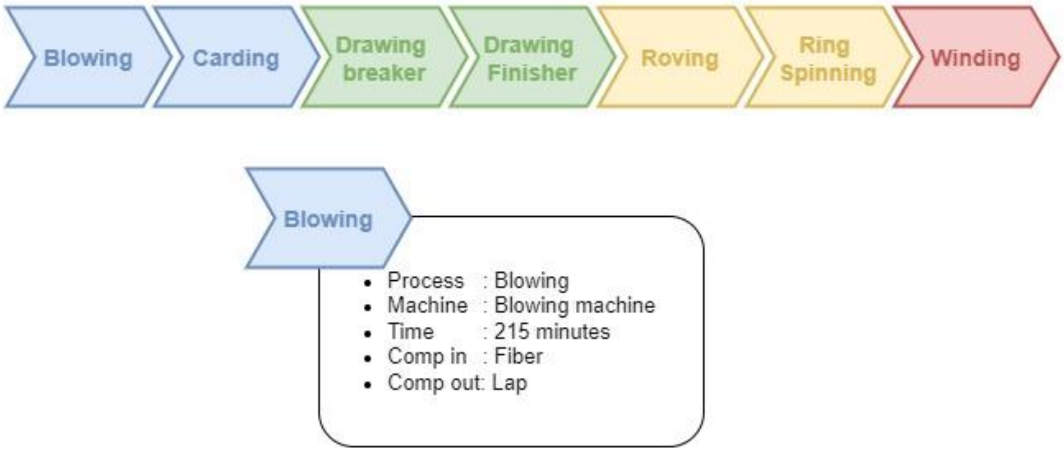

Figure 2. Process model-based product model

Based on ADiMS, each production element in this study has its own operation schedule decided upon during the event on the production floor. Each production element object in the system will decide which operation candidate to work on and when to do the operation candidate when an event happens. The production element's object won't make a choice if it is unable to choose a candidate for the operation (either because it is completing another operation during the decision-making process or because all the operations have been finished).

The coordinator object then transmits the decision made by the production element objects that choose each other, creates an operation schedule based on that suggested schedule, and rejects the decision made by the production element objects that do not choose each other after every one of the production element objects finishes making their decisions. After that, the operation schedule will be stored in the database. This cycle of decision-making will continue until nobody makes a choice. Only the production elements of the product and the production elements of the machining cells (in this example, the production machine) can make decisions regarding the system being discussed. The submission of orders and the end of an operation are instances of events that can prompt decision-making. The activity diagram for the scheme described above is shown in **Figure 3**.

Python programs are used to simulate the scheduling system for yarn production. This program is made based on the object-oriented programming concept that came with the Python programming language. Each production element is modeled as an object in Python programming, and this object is made to have the ability to make decisions based on the ADiMS concept. Another program is made to accommodate the coordinator object in the ADiMS concept; this program has the ability to collect the decision that the production element object has made and save the decision if the machine and product object's decision matches.

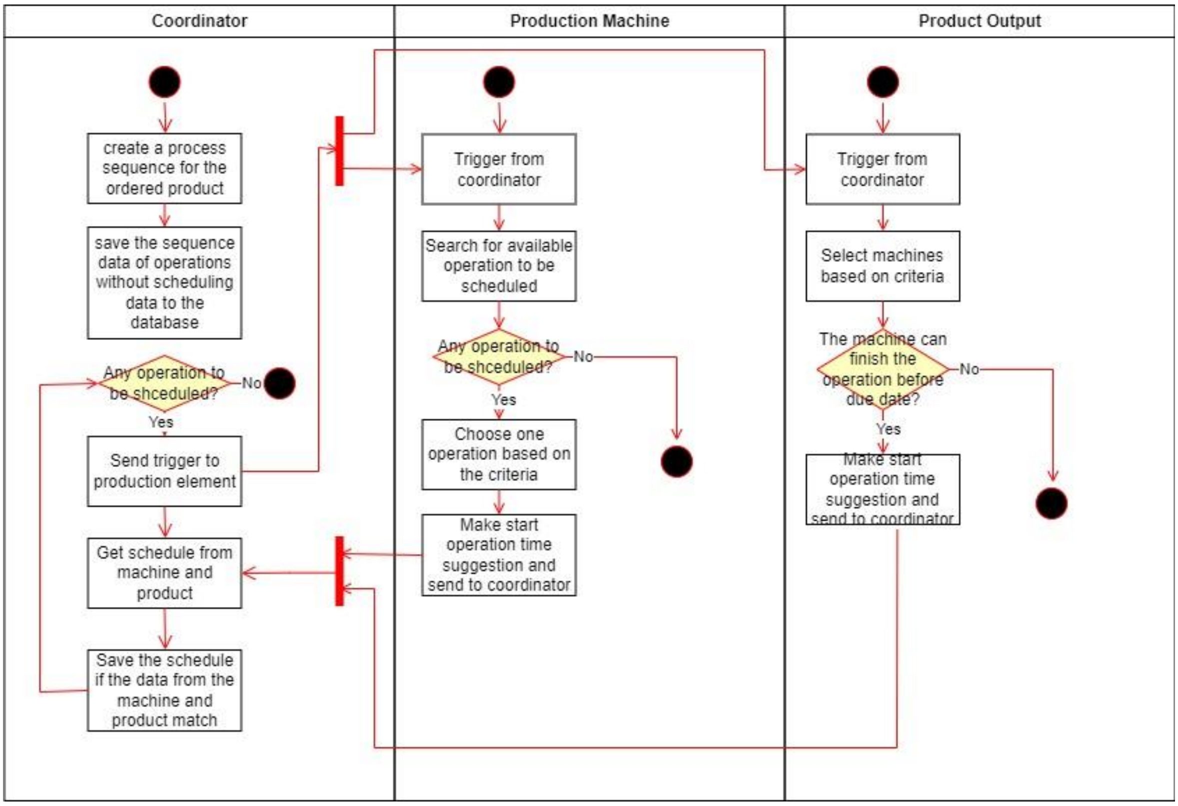

Figure 3. Activity diagram for each production element

3. RESULT AND DISCUSSION

The simulation is set up to have 31 machines that are ready to be used for production scheduling, as seen on **Table 1**. There are 2 blowing carding machines, 8 drawing machines, 10 ring spinning machines, 6 roving machines, 4 winding machines, and 1 packing station. Each of these machines will do the specific process based on its capability. The duration of each process is shown in **Table 2**. For the scheduling simulation, the production will have 2 types of products: cotton yarn and rayon yarn. These 2 products will use different machines for each process. These criteria will affect the scheduling process.

Table 1. Machines in simulation

No	Code	Name	No	Code	Name
1	BC101	Blowing carding RC/cotton	17	RS107	Ring Spinning RC/cotton 7
2	BC201	Blowing carding Rayon	18	RS201	Ring Spinning Rayon 1
3	DB101	Drawing breaker RC/cotton 1	19	RS202	Ring Spinning Rayon 2
4	DB102	Drawing breaker RC/cotton 2	20	RS203	Ring Spinning Rayon 3
5	DB201	Drawing breaker Rayon 1	21	RV101	Roving RC/cotton 1
6	DB202	Drawing breaker Rayon 2	22	RV102	Roving RC/cotton 2
7	DF101	Drawing finisher RC/cotton 1	23	RV103	Roving RC/cotton 3
8	DF102	Drawing finisher RC/cotton2	24	RV104	Roving RC/cotton 4
9	DF201	Drawing finisher Rayon 1	25	RV201	Roving Rayon 1
10	DF202	Drawing finisher Rayon 2	26	RV202	Roving Rayon 2
11	RS101	Ring Spinning RC/cotton 1	27	WD101	Winding RC/cotton 1
12	RS102	Ring Spinning RC/cotton 2	28	WD102	Winding RC/cotton 2
13	RS103	Ring Spinning RC/cotton 3	29	WD201	Winding Rayon 1
14	RS104	Ring Spinning RC/cotton 4	30	WD202	Winding Rayon 2
15	RS105	Ring Spinning RC/cotton 5	31	PC001	Packing
16	RS106	Ring Spinning RC/cotton 6			

Table 2. Processes and duration of each process

Process Code	Duration (Minutes)	Name	Process Code	Duration (Minutes)	Name
BC11	215	Blowing carding RC/Cotton	BC21	430	Blowing carding Rayon
DB11	305	Drawing breaker RC/cotton	DB21	305	Drawing breaker Rayon
DF11	330	Drawing finisher RC/cotton	DF21	330	Drawing finisher Rayon
RV11	165	Roving RC/cotton	RV21	330	Roving Rayon
RS11	250	Ring Spinning RC/Rayon	RS21	525	Ring Spinning Rayon
WD11	250	Winding RC/Cotton	WD21	525	Winding Rayon
PC00	150	Packing RC/Cotton	PC00	150	Packing Rayon

The simulation will try to schedule 5 cotton yarn products and 2 rayon yarn products. The first scheduling simulation of a one-yarn cotton product (code 1) that starts at 11.40 am and ends at 3.25 pm is shown in **Figure 4**. The product will be processed in a Blowing carding RC/cotton machine (code BC101), a drawing breaker RC/cotton 1 machine (code DB101), a drawing finisher RC/cotton 2 machine (code DF102), a Roving RC/cotton 2 machine (code RV102), a Ring Spinning RC/cotton 4 machine (code RS104), a Winding RC/cotton 1 machine (code WD101), and a Packing station (code PC001). As can be seen in the picture, the processes to make cotton yarn have been sucessfully made. The scheduled process is in accordance with the planned sequence, and the selected machine is in accordance with the machine's ability to process materials.

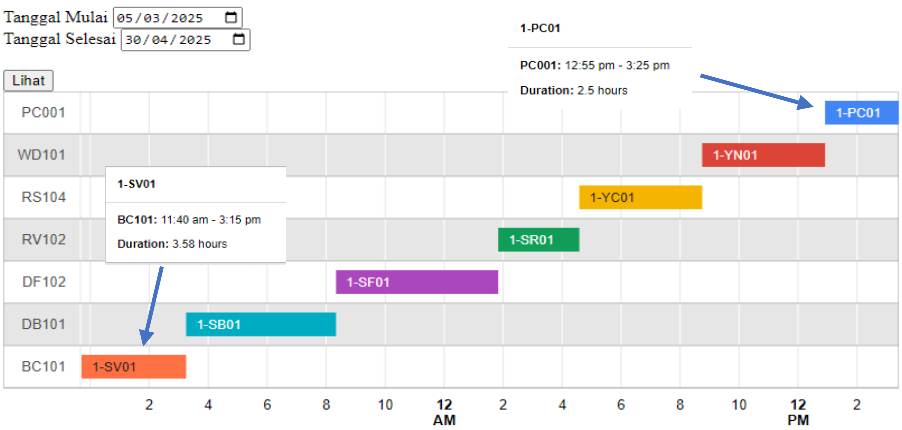

Figure 4. Scheduling first yarn cotton product

The second scheduling simulation (code 2) is shown in **Figure 5**. The first process of the second yarn cotton product starts in the blowing carding RC/cotton machine (code BC101) right after the first process of the first yarn cotton product in the blowing carding RC/cotton machine (code BC101). They use the same machines because there is only one simulated blowing-carding RC/cotton machine. The other processes for second yarn cotton products are made in a drawing breaker RC/cotton 2 machine (code DB102), a drawing finisher RC/cotton 1 machine (code DF101), a roving RC/cotton 3 machine (code RV103), a ring spinning RC/cotton 3 machine (code RS103), a winding RC/cotton 2 machine (code WD102), and a packing station (code PC001). These machines are different from the first yarn product; the selected machines are available and do not have any scheduled process.

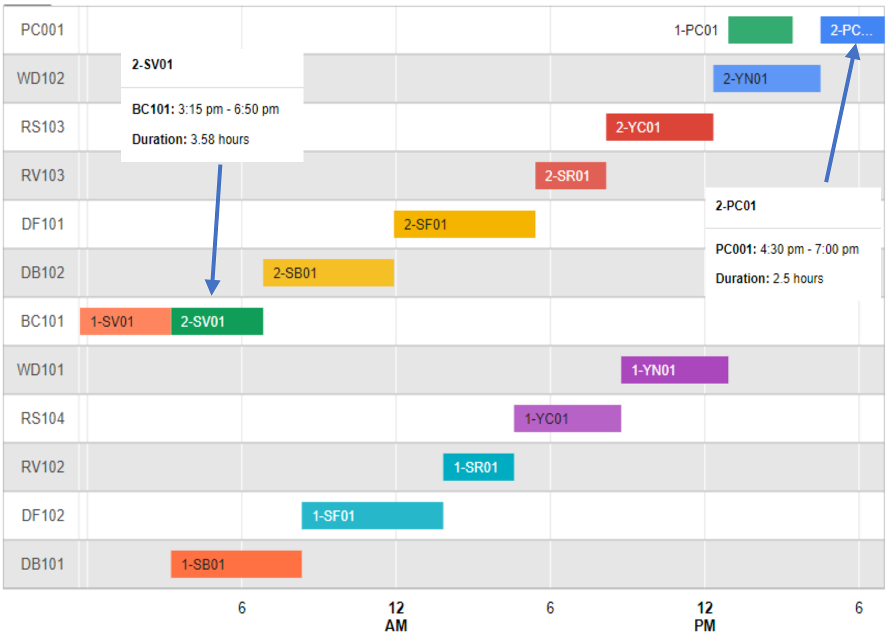

Figure 5. Scheduling second yarn cotton product

After that, the scheduling simulation is made for 3 other yarn cotton products (codes 3, 4, and 5), with a total of 5 scheduling of 5 yarn cotton products having been made as shown in **Figure 6**. These processes are scheduled on the machine that can start the next process earliest. These processes do not collide with other processes and still follow the appropriate process sequence.

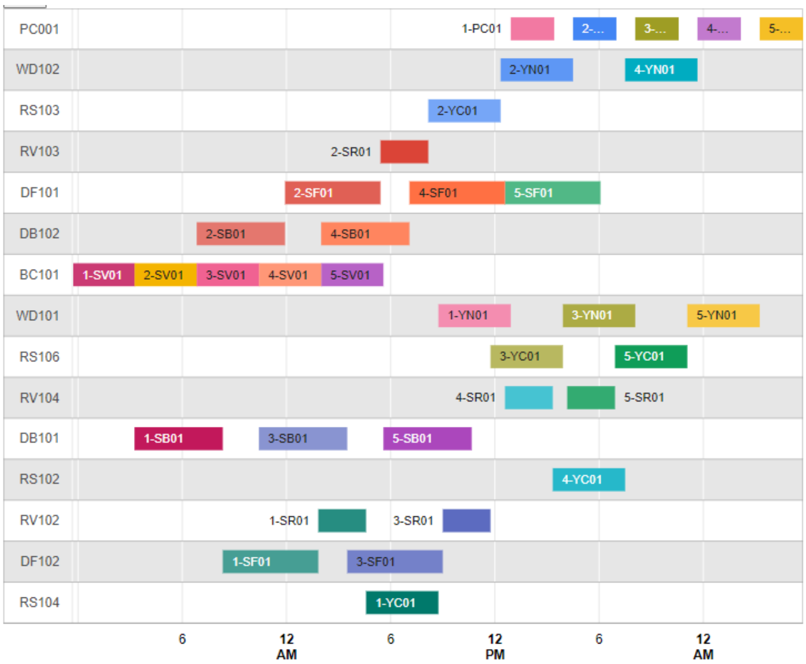

Figure 6. Scheduling of 5 yarn cotton products

After that the program tried to schedule 2 yarn rayon products (codes 6 and 7), which are different from the 5 last products that have been scheduled as can be seen in **Figure 7**. The machine that used to make rayon yarn should be different from the machine that makes cotton yarn. The result was as expected. The machines that are used in scheduling 2 yarn rayon products are the Blowing Carding Rayon machine, Drawing Breaker Rayon 1 machine, Drawing Finisher Rayon 2 machine, Roving Rayon 2 machine, Ring Spinning Rayon 4 machine, Winding Rayon 1 machine, and Packing Station.

Figure 7 Scheduling of 5 yarn rayon products

All the results from the scheduling simulation meet the desired criteria. Each variant of the product is scheduled in a suitable machine that can process the specific product, no schedules clash with each other, and the process sequence for making one product is correct based on the reference sequence to make the yarn. The program tries to find a machine that can start the process as quickly as possible by choosing a machine that is available right after the previous process. Even if the scheduling concept that is based on ADiMS is not resulting in the most optimal schedule, the result is very flexible and efficient to be used on the shop floor because for each product, the scheduling process is less than a minute. Reference [17] with the YFADI Decision Support System and refernce [18] with Heuristic lot size scheduling, while considering the uniqueness of textile manufacturing, tried to manage the yarn production with a central decision-making process, which, compared to distributed decision-making processes, will take a longer time to process. Mathematical programming models for aggregate production planning are discussed in [19] with the advantage of providing an optimal solution for executing a production plan, but they are not agile to any conditional changes that can happen in the production unit.

4. CONCLUSION

The operation scheduling system with the Autonomous Distributed Manufacturing Systems (ADiMS) concept for yarn production has been created and simulated in a virtual environment and shown the operation schedule that fits the desired criteria. This system is trying to solve how to make the scheduling process more effective and efficient by utilizing digital twin and Industry 4.0 technology. The simulation shows that the method of scheduling is very flexible and efficient to be used on the shop floor. Further research could be discussed about handling scheduling anomalies like machine breakdown and decision-making to reschedule to accommodate sudden events.

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