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Improving Just-in-Time manufacturing operations by using Internet of Things based solutions

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Abstract

Just in time (JIT) manufacturing is one of the main methodologies used to enhance manufacturers' competitiveness through inventory and lead time reduction. However implementing JIT has some challenges, e.g. lack of required information sharing or communication between stakeholders, insufficient sound action or planning system etc. Internet of Things (IoT) technology has the potential to be used for acquiring data and information in real time to facilitate dynamic JIT manufacturing. This paper presents a research on using IoT based solution to enhance JIT manufacturing. The general challenges of JIT implementation are identified first, then an IoT based solution is proposed to address the JIT challenges in a selected case study. A framework to support the proposed IoT solution is developed and its implementation steps are suggested.

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Keywords: Production Scheduling; Dynamic Scheduling; Real-time resource status monitoring; Just-in-Time manufacturing; Internet of Things; IoT; RFID

1. Introduction

Just-In-Time operations are widely implemented in manufacturing business with the main objectives to control the timeliness of the production and delivery of products while maintaining or improving the quality of products [1]. JIT requires manufacturers to handle tasks within very small time spans and it has big impact on production scheduling.

The developed sensors and wireless network technologies have raised the possibility of incorporating Internet of Things (IoT) technologies into manufacturing process [2]. IoT can link physical elements in manufacturing process, such as materials, work in progress (WIP), finished products, labour, machine, tooling etc., and capture their status & performance so as to support production scheduling. However, how to use that addition information to help production scheduling remains as an on-going research question. This paper presents a work of developing an IoT based framework to enhance JIT manufacturing through addressing specific challenges in scheduling process. The work has the following objectives:

- To identify specific challenges of scheduling process in the JIT manufacturing environment
- To design an IoT based solution for tackling the identified challenges for a selected case study
- To establish a dynamic production planning framework based on the designed IoT based solution

The paper starts with reviewing related research, it is followed by identifying the challenges of scheduling process in JIT manufacturing to bring out the requirement of the framework. After that, through a selected case scenario, an IoT solution based framework to address the identified challenges has been established. At the end, implementation plan for the established framework has been suggested.

Nomenclature

IoT	Internet of Things
JIT	Just In Time
ERP	Enterprise Resource Planning

MES	Manufacturing Execution System
MRP	Material Requirements Planning
BOM	Bill of Materials
DB	Database
RFID	Radio Frequency Identification
WIP	Work In Progress

2. Relevant research of IoT applications in production scheduling

Guo et al. developed a system with remote monitoring and production scheduling functions in a distributed manufacturing environment based on RFID and cloud technology [3]. The system meets the requirements for decision making in very short time with good extensibility and scalability. A framework is created to collect real-time production status of machines and operators in order to monitor manufacturing progress in labor-intensive plants and their suppliers. The collected information from plants is used for remote monitoring at different levels to support decision makings in manufacturing scheduling. Zhang et al. established an architecture to realise real-time scheduling and re-scheduling through RFID technology and multi-agent design [4]. The architecture is connected to MRP II to get order information, while the machine agent is designed to manage and process the real-time data collected through RFID devices to meaningful information (real-time status of the machine) used in scheduling process. The information generated by machine agent is used for assigning tasks to machines by process. Zhong et al. considered another manufacturing planning and scheduling model in an IoT-enabled (RFID) shop floor environment [5]. The model is based on a two-level solution (manufacturing planning and scheduling). The RFID devices in the model are not only used for monitoring the production progress and machine/operator status, but also for delivering the job information to operators.

Geerts et al. demonstrated a way to establish an IoT based supply chain model, which shows the advantages like strong visibility, interoperability and practicality [6]. Chen et al. proposed an RFID-based framework for real-time management of production operations. The framework allows enterprises to integrate RFID-based solutions into their information technology infrastructure and manufacturing environment [7]. Poon et al. developed an RFID-based decision support system to monitor the status of manufacturing facilities in a shop floor in real-time [8]. Ngai et al. developed an RFID-based system for monitoring and tracing aircraft repairable items in an aircraft engineering company [9]. Wang et al. used RFID and Internet technologies for monitoring and control of production systems within a manufacturing company. They developed a system with remote connection feature, which can monitor manufacturing progress in distributed environment such as supply chain [10].

Despite existing research on frameworks/architectures to collect real-time information from shop floor and generate scheduling solutions based on the collected information, the existing frameworks and architectures don't consider

comprehensive manufacturing resources' variability, e.g. tooling, material logistic, one operator for n workstations scenarios etc. Studies have rarely been seen on the applications of IoT technology in dynamic scheduling during the production process while there are changes of customer orders. This paper intends to develop a comprehensive dynamic scheduling framework in JIT manufacturing environment based on IoT technology.

3. Scheduling process in JIT manufacturing

3.1. The challenges of JIT manufacturing

Jadhav J. etc. discussed the main challenges of JIT manufacturing [11]:

- Absence of a sound action or planning system
- Lack of information sharing or communication with stakeholders
- Cross-functional conflict

3.2. General production scheduling process flow

General production scheduling process flow for a manufacturing company based on ERP system for material requirement management is shown in Figure 1.

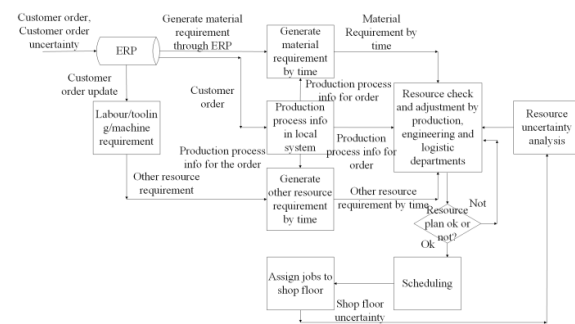


Fig. 1. General scheduling process flow

In figure 1, the responsibility of ERP system is to receive customer order and convert the order to material requirements. The “Labor/tooling/machine requirement” module is to generate resource requirements for the customer orders through local ERP/MES or manually (for manufacturing resources except materials). The “resource requirement by time” module refers to the sub-requirements for each production process with sequential order of process steps. “Production process information” (required resources for each process, standard resource holding time etc.) needs to be broken down to the general resource requirements for each individual process step and time slot. The “Resource check and adjustment” process checks the availability of those required resources in real time during production, and the production schedule is created if the resource plan could meet the production requirements. The broken-down schedules by

process are assigned to the machines and operators by a local IT system or using hard copies format.

During production, situation of planned resources may vary because of various reasons. The main reasons are the customer order change and resource availability change. Customer order changes may include changes of order due date, volume and product ID; Resource availability change may be caused by machine break down, labor unavailability etc. The resource check process would be triggered whenever there is an update on resource availability.

3.3. Impact of JIT manufacturing features on scheduling

The features of JIT manufacturing system have impact on scheduling process in the following aspects:

(a) Inefficient resource checks and schedule process

There is high possibility to re-schedule the orders, and the rescheduling process takes time and could have several departments involved for complex orders. Furthermore, the extra time caused could challenge the small margin of JIT manufacturing.

(b) Risks in on-time material delivery from suppliers

Successful implementation of JIT manufacturing relies on suppliers because it needs more on-time material delivery in small batches. It could take long time to develop suppliers to meet the requirements when a mature supplier fails to make required delivery on time.

(c) Cross-function conflict

Scheduling process is a cross-function process where several departments are involved. Conflict between different departments can be amplified, and poor process transparency could make it even worse.

4. Develop a Dynamic Scheduling Framework

For developing a dynamic scheduling framework, a case is selected based on an automotive component manufacturer who produces harness parts in cars. The company has been implementing the JIT manufacturing system for nearly a year. The company's main customers also have implemented the JIT system so that this company can receive small batch order in more frequent basis. The company orders required materials in two ways: common materials are ordered in big batch and build up inventory in the plant, whilst other materials are ordered when customer order is received and inventory of required materials is low in the plant. Both types of ordered materials are transported by lorry. The suppliers deliver materials by package, same type of materials use the same type of containers with the same package volumes and quantities. Most production processes within the company are machine based, and some processes require tooling such as dies, and fixtures etc. The tooling are stored in the tooling centre when they are not used, and they are delivered to the machine when required (One tooling can be shared by multi machines). The machines require operators to operate, and some machines can share operators. The operators' skills are

certified by the company and being recorded in the labour skill matrix that stores match of skills to specific manufacturing process. The company uses ERP system for material planning and local system as MES (manufacturing execution system). The ERP system stores the customer order (product ID, volume, due date), supplier information, latest BOM (bill of material) and convert the received customer order to requirements for required materials. The production process information are stored and maintained in the local system. The assigned schedule is loaded and stored in the local system and the system can send the breakdown schedules to the individual machines and the operators' PDAs. The local system installed in a machine has the function of monitoring the jobs progress on it.

A framework for dynamic scheduling in JIT manufacturing based on the selected case should have the following function: Automatic and accurate resource check and dynamic scheduling functions; timely material delivery status sharing between the company and suppliers; timely resource and scheduling information sharing among departments within the company.

An IoT technology based framework has been established by adding two functional modules to the original local system. The two added modules are real-time resource status monitoring module and dynamic scheduling module. In relation to the two added modules, the process "generate the resource requirement by time" needs to be updated to automatic process. The established dynamic scheduling framework is illustrated in Figure 2.

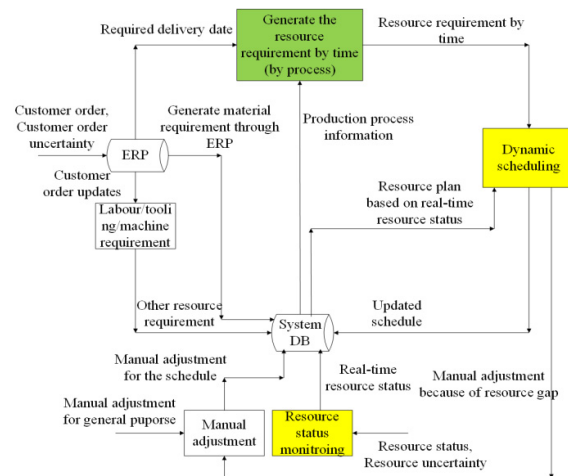


Fig. 2. Overall scheduling system framework

The specific information required for dynamic scheduling in JIT manufacturing is identified as below:

- Actual production cycle time by process
- Machine status
- Tooling status
- Material delivery status
- Labor status

(a) Actual production cycle time by process

The production cycle time of each process is captured by machine via recording the process start and end time, the cycle time is updated in real time and stored in the database of local system.

(b) Machine status

The local system identifies the machine status as Idle (no job allocated and the machine indicates it is not running), Stop (have job allocated but it is not running) or Running, and the local system provide interfaces to operators for identifying and indicating reasons of machine stops such as changeover, maintenance or breakdown etc.

(c) Tooling status

All the tooling are stored in the tooling centre in the plant when they are not used. The possible locations of tooling are: in tooling centre, on machine or in delivery. RFID devices are used to identify the location of tooling (RFID tags are attached to the tooling) and the tooling status can be indicated by operators via RFID devices. RFID readers are installed on machines, and tooling can be detected when they arrive at the machine. RFID readers installed in entrance and exit gates of the tooling centre are used to detect if a tooling is in the tooling centre.

(d) Material delivery status

Monitoring material delivery status requires cooperation with suppliers. A RFID based solution can be set in transportation lorry to capture material delivery status. The solution include: Label the packages with RFID tag (each tag has unique identity number) before loading them onto the lorry; Set corresponding relation of material ID and RFID tag ID in advance, and send them with the material order ID and package size to the local system of machine once the loading is finished; Install a GPS enabled PDA (being able to connect to 3G/4G wireless network) on the lorry; Install a RFID reader on the lorry and connect the reader to the PDA so that the PDA can get information from RFID reader in real-time. By using this RFID based solution, the PDA get the RFID tag ID through RFID reader; the GPS tracker in the PDA generates real-time location of the lorry; the location and material information in the lorry can be obtained by the PDA. This collected information can be sent to the local system through 3G/4G mobile network. The local system can generate the estimated arrival time of the required materials based on real-time weather and traffic condition. The mean time for unloading, inspection and moving packages to shelf are added on top of the arrival time to estimate the materials' ready time.

(e) Labor status

The production operators can work in different machines. RFID readers are installed on each machine and RFID tags are attached to operators' identity cards. The local system can detect if an operator is in front of any and which machine. By monitoring the machine status, the scheduling system could tell if an operator is in idle or in working status. Operators' "rest" status can be detected when their worn identity card

passes a RFID reader in rest zones. If an operator is not detected in either of the areas mentioned above, and there is no records of his/her leave in the local system, the status would be indicated as "absence".

In order to achieve dynamic scheduling by using the collected information, a real-time resource status monitoring module and a dynamic scheduling module need to be developed:

(a) Real-time resource status monitoring

For real-time resource status monitoring, two applications named as "resource status report" and "resource status monitoring interface" need to be developed, they are shown in Figure 3.

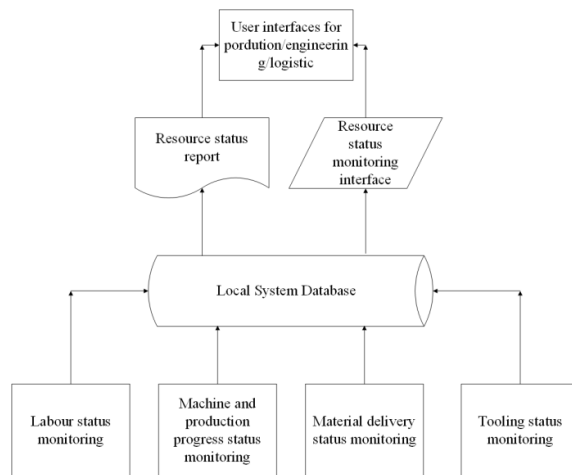


Fig. 3. Real-time resource status monitoring module

The collected resource status would be uploaded to database in local system and the "resource status report" can be generated by local system. By analysing the collected data, more information can be obtained such as machines' average cycle time and down time. A "resource status monitoring interface" is provided on web to allow users to find the collected data from shop floor easily.

(b) Dynamic scheduling

The dynamic scheduling and the automated "generate resource requirement" process is illustrated in Figure 4.

"The required delivery date (time)" is given by the customer order information in ERP system, and the "required types and available hours of the resources" refer to two important data sets:

Required resource type: Type of resources a customer order requires, e.g. type of machine, material ID, tooling ID etc.

Required available hours: The holding time of required resources for a production process, e.g. production process "x" may need machine A for the first 2 hours and tooling "B" for the 0.5 hours from the beginning of production.

These two data sets can be provided by the production process information in the local system database.

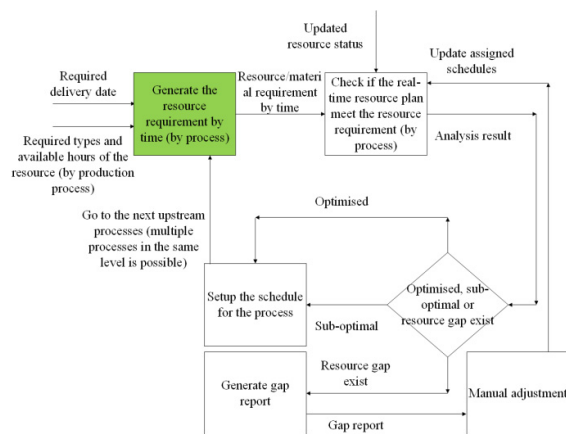


Fig. 4. Dynamic scheduling module

In Figure 4, “Generate the resource requirement by time” process is to generate requirements for resource (materials, machines, labors and tooling) per time slot, which are the reference of automatic resource check. This process is explained below:

The required start time of the last production process is calculated based on the “required delivery date (deadline)” and the standard operation time of the production process, consequently the holding time of required resources for the process can be calculated in the format shown in Table 1. The materials don’t have end time in Table 1 means they are consumables, but they still have associated start time as they are needed for starting the production process.

Table 1. Required relative holding time of resources

Process ID	Resource type	Resource ID	Relative holding time(hours) (production start time is datum point)	
			Start	End
21	Material	0001	0	/
21	Machine	1002	0	2
21	Labour	3011	0	2
21	Tooling	2354	0	1
21	Tooling	2025	1	2

The required delivery date (deadline) and the relative holding time identified above are used for working out the “resource/material requirement by time” for the last scheduled production process as presented in Figure 5.

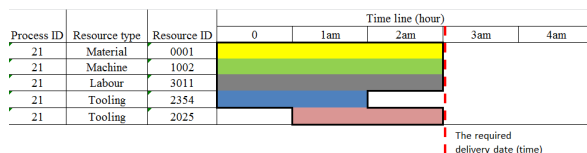


Fig. 5. Resource/material requirement by time

In Figure 5, the relative holding time is outlined in black, when the right side of the outline touches the delivery time, it means that combination is the optimised schedule, which means a JIT production (no tardiness and no earliness). If actual resource plan doesn’t fit into the optimised schedule, the last production process could start earlier, which moves away from the required delivery time but still have the same resource requirement.

For the rest of processes planned for a customer order, “the required finish time” depends on the downstream processes, which means those processes can only be scheduled when the downstream processes have been scheduled. The last process always needs to be scheduled first.

The process “Resource check and schedule set” would generate/update resource plan and compare it with the resource requirement. If the comparison shows the resource plan meets the requirement, production schedule would be set. To update the resource plan based on the real-time resource status and the latest version of schedule assigned to shop floor, it needs to break down production schedule to individual process schedules, and compare the real-time progress of the individual process to the assigned individual schedule. The resource/material plan is updated based on the comparison results. An example of the updated resource/material plan in comparison with Figure 5 is shown in Figure 6.



Fig. 6. Real-time resource/material plan

A gap report is generated based on the resource gap found out in the resource check process. The local system would send mails to relevant employees in different departments if the gap report is updated.

Once the gap report is sent, relevant people need to react to it immediately, possible reactions include: Adjust the assigned schedule to make the resource plan fit into the resource requirement or adjust the working hours of machine and labor to available resource for the requirement.

As received orders from customers may change, modification of orders may be needed and recorded in the ERP system. The ERP system would send updated orders to the local system. Relevant operators would receive a reminder from the local system and they need to decide if let the system recognise the order as a brand new one that can be assigned a new schedule (normally old version order doesn’t start production in this case), or they manually adjust the order (could adjust it in the process level). Resource status can be updated in real-time by using resource status monitoring module. When a change of resource plan has been detected, the resource check process would be triggered to check if there are resource gaps and the assigned schedules need to be updated.

5. Develop implementation plan for dynamic scheduling framework

5.1. Implementation plan

In the dynamic scheduling framework, the real-time resource status monitoring module should be implemented first because its output is to be used in dynamic scheduling. The implementation plan for other modules is based on three factors: Easiness of implementation, benefit brought by the modules, and the relations between those modules (if any module is the precondition of other modules). Implementation sequence of the functional modules within the framework is recommended in Table 2, potential users may adjust priority to suit their specific business environment.

Table 2. Real-time resource/material plan

New added module	Sub-module	Sequence
Resource status monitoring module	Machine production progress and status monitoring	1
	Tooling status monitoring	2
	Material delivery status monitoring	3
	Labour status monitoring	4
	Resource status monitoring interface	5
	Resource status report	5
Dynamic scheduling module	Generate resource/material requirement by time	7
	Resource check	8
	Resource gap report	9
	Schedule setup	10

5.2. Mitigation of implementation challenges

As the dynamic scheduling framework is vital for the production process after implementation, some challenges may occur and mitigation plan is needed to reduce risk and enhance efficiency.

To reduce risk: Backup plan should be in place for deploying this dynamic scheduling framework, so that if the implementation incurs any problem, the company can switch back to the original manual scheduling system. Backup plan requires the system to provide important data to recover. Trouble shooting documents should be provided in shop floor in order to solve potential occurring problems quickly, and contacts should be given along with the trouble shooting documents.

To enhance efficiency: Top management commitment is crucial. All users of the dynamic scheduling framework are encouraged to identify potential problems and suggest improvements. Adjusting performance measurement for involved stick holders need to be considered for implementing the dynamic scheduling framework as part of a change management within the business.

6. Conclusion

An IoT technology based dynamic production scheduling framework has been developed for JIT manufacturing environment based on a case scenario about automotive component manufacturing. Specific challenges of scheduling

in JIT manufacturing have been identified. The developed dynamic scheduling framework is based on the original local MES system with two additional proposed functional modules: real-time resource status monitoring and dynamic scheduling. The proposed framework can response to the dynamic changes with customer orders, production progress, and availability of required resources. This allows manufacturers to adjust planed schedules during production to maximize the production outputs with limited resources. An implementation plan for deploying the dynamic scheduling framework is developed based on the consideration of factors such as easiness of implementation, benefit brought by the proposed modules, and the relations between the modules.

The future work of this research would build a demonstrator of dynamic scheduling system and simulate it on some cases scenarios. After that, a real dynamic scheduling system needs to be built and tested it in real production operations.

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