

A Real-time Planning and Scheduling Model in RFID-enabled Manufacturing

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Abstract

As the increasing use of RFID technology in manufacturing companies, the real-time production data collection is inadequate. Companies especially small and medium-sized manufacturing entities, contemplate to implement advanced planning and scheduling (APS) so as to achieve real-time production. This paper, motivated by a real-life case, proposes a real-time planning and scheduling model to realize meaningful APS in the RFID-enabled manufacturing environment. Experiments results show its outperformance over other three rule-based approaches used by the case company. Based on this model, a real-time Kanban is adopted for supporting the coordination between planners and schedulers in the real-world ambience.

Keywords

Advanced Planning and Scheduling, RFID, Real-time, Rules, Shop floor Manufacturing

1. Introduction

Real-time production planning and scheduling refers to allocate various manufacturing resources like labours, equipment and materials to tasks through efficient and effective ways to meet certain performance requirements [1]. However, in most practical environment, planning and scheduling are ongoing reactive processes where a variety of unexpected disturbances is usually inevitable. The static approaches, developed to solve this problem, are often impractical in real-life cases [2]. Advanced planning and scheduling (APS), adopted the dynamic scheduling principle, has been increasingly used in the manufacturing companies where unpredictable events may cause changes in the scheduled plans and feasible schedules may turn infeasible when they are carried out in shop floors [3]. However, the development of APS is limited since it requires perfect data to generate perfect decisions [3-6]. The companies have no such real-time production data collection manners in place [7]. Therefore, manual operation-based APS dominates these companies which have faced large number of difficulties [8].

In order to facilitate the production data capture, radio frequency identification (RFID) technology has been used [9-23]. Using the RFID, large number of manufacturing data could be real-timely collected. These data include the statuses and availabilities of various manufacturing objects such as equipment, labors and materials which are deterministic throughout the production processes [24, 25]. The information is able to support actual and meaningful APS which is regarded as an adaptive system that can handle any disturbances from the manufacturing sites so as to meet constrains like delivery date or makespan etc [6].

One of the key elements to implement the APS in RFID-enabled manufacturing environment is a real-time planning and scheduling model. To this end, this paper introduces such a model which integrates a real-life case that has been used RFID for supporting its shop floor production over five years. This model is based on two key concepts: hybrid flow shop (HFS) and real-time job pool, which are used for facilitating the production planning and scheduling within the RFID-enabled ambience such as shop floor manufacturing [26, 27].

Several research questions are concerned in this paper. The first question is what strategies could be used in production planning level to meet the objectives such as minimization of delay etc. The second question is what objectives should be set in the scheduling level and what working mechanisms could be adopted so as to satisfy

both the objectives from planning and scheduling level. The third question is how the planning and scheduling level interact with each other to ensure the plans and schedules could be carried out strictly in execution.

This paper examines several strategies used in the case company so as to figure out which strategy is suitable for a certain conditions firstly. Secondly, in scheduling level, several objectives such as total tardiness, makespan and maximization of equipment utilization are proposed following a backward propagation strategy. Finally, with the assistance of RFID technology and a real-time Kanban, planning and scheduling parties could interact and their executions are controlled. In case of disturbances such as equipment breakdown, a warning will be sent and the processing jobs could be adaptively re-arranged or manually intervened.

The rest of this paper is organized as follows. Section 2 outlines the real-time manufacturing environment where problem descriptions are summarized. These problems come from a real-life manufacturing company. It focuses on reporting the RFID-enabled real-time shop floor manufacturing environment and the key working principles. Section 3 introduces the planning and scheduling model which is based on the research background so as to achieve real-time production. Section 4 reports on the experiment from a numerical study so as to unravel the feasibility and practicality of the proposed model. A real-time coordination mechanism is reported using the Kanban system. Section 5 concludes this paper by giving our findings and future work.

2. Problem Description

A. RFID-enabled Shop floor Production

The research background is based on a real-life RFID-enabled shop floor production which could be simplified as Figure 1. The establishments like the deployment of RFID readers, tags, communication networks are followed a strategic approach [26]. A real-time Kanban plays an import role in coordinating the production planning and scheduling within the RFID-enabled shop floor manufacturing environment [28].

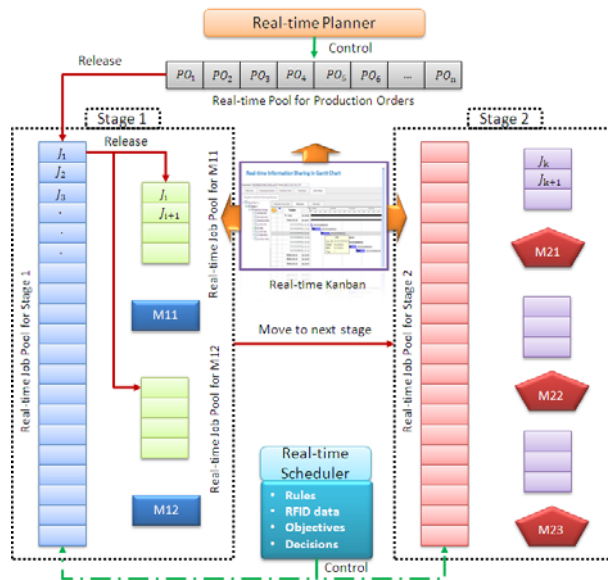


Figure 1. RFID-enabled real-time shop floor production.

The operation within the above production environment (regarded as HFS in this paper) contains several steps. First of all, in planning level, production orders are controlled by a real-time planner which is responsible for sequencing them in an optimal to meet the objectives. Secondly, in scheduling level, the sequenced production orders are converted into jobs managed by a real-time job pool for the 1st stage. Actually, a production order is split into several jobs each of which carries 180 pieces. Thirdly, the real-time job pool for the 1st stage releases jobs to a real-time job pool for individual equipment when the operator read his/her RFID staff card (a tag) to get jobs. He/she read the tags attached on the materials to get job instructions and other required information. Fourthly, when the operator finishes a job, he pats his staff card to inform the delivery of materials. Meanwhile, the job enters the job pool for next stage automatically. The four steps will be carried out continuously within the production shop floor until a job reaches the end manufacturing stage. The production planning and scheduling problem within the RFID-enabled environment can be described as two levels: planning and scheduling.

B. Production Planning

In production planning, a set of production orders $PO = \{PO_1, PO_2, \dots, PO_n\}$ should be sequenced in a suitable and optimal manner. Several objectives such as total tardiness $\sum Tardiness$ etc. should be satisfied. Here, this paper considers the changeover time of equipment tools (CT) that is because different products should be processed by different equipment tools according to their materials. This time greatly affects the total processing time. In this case, CT takes a certain proportion of time when considering the production planning. This paper analysis the quantitative aspects of the influence of CT on the planning level decision-making. Each PO_i , $1 \leq i \leq n$ has several attributes which are expressed by a set which is regarded as variables in the models proposed in this paper.

C. Production Scheduling

In production scheduling, a set of jobs $J = \{J_1, J_2, \dots, J_n\}$ should be sequenced. Jobs are split from PO each of which may divided into several jobs. That means jobs from a specific PO have the same priorities, due date, product category etc. Jobs are managed in the real-time pools for various stages. The most important concern is the first stage because the following stages (stage 2, 3... K) are based on the accomplishment of jobs in stage 1, real-time RFID information as well as various dispatching rules.

3. A Real-Time Planning and Scheduling Model

A. Assumption

This paper considers the model under several assumptions which are listed as follows:

- 1) Production orders could be released to the first manufacturing stage thoroughly.
- 2) Time spent on changeover of equipment tools will be considered when processing jobs with different materials.
- 3) There are five degrees for the priority system expressed by integer 1, 2, 3, 4, and 5 which is with the smaller value represented higher priority.
- 4) Each job/batch has a standard quantity-180 pieces.
- 5) Jobs are released to equipment through RFID event-driven mechanism.
- 6) Time spent on material delivery is ignored.
- 7) Equipment operators are not concerned.
- 8) Once a job is started, it cannot be stopped unless the equipment breakdown.
- 9) This model allows emergency orders and manual intervenes on real-time job pools.
- 10) The buffers are unlimited.

B. Formulation

Indices and sets

PO	set of production orders
J	set of jobs
PO_i	production order i
CT	changeover time of tools
N	total number of PO
J_i	job i
M	total number of J
K	total number of stages
L_i	total number of equipment in stage i
η	number of tool changeover
U_{ij}	capacity of equipment j in stage i

Input variables

P_i	processing time of PO_i
ω_i	weight of PO_i (priority)
ST_i	setup time of PO_i

S_i	start time of PO_i
F_i	finished time of PO_i
d_i	due date of PO_i
Q_i	quantity of products in PO_i
PT_i	raw-material type of PO_i
P_i	processing time of J_i
ST_i	setup time of J_i
S_i	start time of J_i
F_i	finished time of J_i
ω_i	weight of J_i (priority)
d_i	due date of J_i
t_{ijk}^1	RFID time stamp of job i obtained at stage j by machine k
t_{ijk}^2	RFID time stamp of job i finished at stage j by machine k
Q_i	quantity of items in J_i
PT_i	raw-material type of J_i
ms_i	$= \begin{cases} 1 & \text{if equipment i is} \\ 0 & \text{otherwise} \end{cases}$
σ_{ijk}	$= \begin{cases} 1 & \text{if job i is processed at stage j} \\ & \text{on equipment k} \\ 0 & \text{otherwise} \end{cases}$

Objective functions and constraints

- Planning level

$$\text{Minimize } \sum_{i=1}^N (F_i - d_i) + \eta CT \quad (1)$$

Subject to.

$$1 \leq \omega_i \leq 5, \text{ integer} \quad (2)$$

$$1 \leq Q_i \quad (3)$$

$$0 \leq \eta \leq N \quad (4)$$

$$\sum_{i=1}^N P_i \leq \max(d_i) \quad (5)$$

$$F_i = S_i + ST_i + P_i \quad (6)$$

$$\sum_{i \in N} ms_i = L_i \quad (7)$$

- Scheduling level

$$\text{Maximize } \sum_{i=1}^K \sum_{j=1}^{L_i} U_{ij} \quad (8)$$

Subject to.

$$P_i' = \lfloor P_i / \lceil Q_i / 180 \rceil \rfloor \quad (9)$$

$$\omega_i' = \omega_i \quad (10)$$

$$d_i' = d_i \quad (11)$$

$$PT_i' = PT \quad (12)$$

$$Q_i' = 180 \quad (13)$$

$$F_i' = S_i' + ST_i' + P_i' \quad (14)$$

$$t_{ijk}^1 \leq ST_i' \quad (15)$$

$$t_{ijk}^2 \leq F_i' \quad (16)$$

$$\sum_{i \in N} \sigma_{ijk} = J \quad (17)$$

$$M \geq \left\lceil \frac{\sum_{i=1}^N Q_i}{180} \right\rceil \quad (18)$$

$$\sum_{i=1}^M \sum_{j=1}^K \sum_{k=1}^{L_j} t_{ijk}^2 \leq \sum_{i=1}^N F_i \quad (19)$$

In the formulation, key concerns of planning and scheduling level are covered. In planning level, Eq 1 considers the minimization of total tardiness and the time spent on changeover. Constraint 2 defines the weight of each production order. Constraint 3 determines the quantity for each order and constraint 4 confines the boundary of number of tool changeover. Constraint 5 ensures the solution space. Constraint 6 defines the finished time. Constraint 7 guarantees that each order must be processed.

In the scheduling level (1st stage), Eq. 8 concerns the maximization of equipment utilization in each stage. Constraint 9 defines the processing time in a specific stage with an equipment. Constraints 10 to 13 reflect the relationship and interaction with planning level. Constraint 14 unravels the finished time for each job. Constraint 15 and 16 indicate that the real-time production activities could be ensured to execute the planned and scheduled results strictly. Constraint 17 ensures that every job can be processed and 18 guarantee the satisfaction of product quantities ordered from customers and certain level of WIP. Constraint 19 guarantees the delivery date of all production orders.

Theorem 1. If $\sum_{i=1}^N P_i > \max(d_i)$, then $\exists k, 0 \leq k \leq N, \sum_{i=1}^k F_i - d_i > 0$.

Proof.

Let $PO_{opt} = \{P_1, P_2, \dots, P_N\}$ denotes an optimal sequence from the model, then $(P_1 - d_1) \leq 0$,

$$(P_1 + P_2 - d_2) \leq 0, \dots, \sum_{i=1}^{k-1} P_i - d_i \leq 0$$

$$\because F_i = S_i + ST_i + P_i$$

$$\therefore F_i > P_i$$

$$\exists k, 0 \leq k \leq N$$

When $\sum_{i=1}^N P_i > \max(d_i)$

$$\sum_{i=1}^k P_i - d_i > 0$$

$$\therefore \sum_{i=1}^k F_i - d_i > 0.$$

This theorem indicates that if the total processing time is bigger than the maximal value of due date. At least one of the production orders must be delayed.

Theorem 2. Let $P_i' = \lfloor P_i / \lceil Q_i / 180 \rceil \rfloor$, then $\sum_{i \in \lceil Q_i / 180 \rceil} P_i' \leq P_i$, $\sum_{i \in \lceil Q_i / 180 \rceil} Q_i' \geq Q_i$.

Proof.

Let a production order PO_i split into $\lceil Q_i / 180 \rceil$ batches (a batch is a job). Each batch has $Q_i' = 180$ and the processing time is $P_i' = \lfloor P_i / \lceil Q_i / 180 \rceil \rfloor$.

If $Q_i \leq 180$, $\lceil Q_i / 180 \rceil = 1$ then $P_i' = P_i$, $Q_i' \geq Q_i$;

If $Q_i > 180$, $\lceil Q_i / 180 \rceil \geq 2$

$$\therefore P_i' = \lfloor P_i / \lceil Q_i / 180 \rceil \rfloor$$

$$\therefore \sum_{i=1}^{\lceil Q_i / 180 \rceil} P_i' \leq P_i$$

Then, $\sum_{i \in \lceil Q_i / 180 \rceil} Q_i' \geq Q_i$ is obvious.

Theorem 2 unravels the relationship between a production order and its related jobs. The total processing time of jobs split from an order is equal and less than a processing time of the order. While, the total quantity of items from batches is equal or larger than the quantity of products in an order. That means, in real-life manufacturing cases, production parties always produce a little bit more items than the requirements from the customers since there are some defects and emergency orders. Keeping a certain level of WIP is necessary and significant in such situations.

Table 1: Production Orders

PO_i	1	2	3	4	5	6	7
P	6	18	12	10	10	17	16
ω	1	5	2	4	1	4	2
d	8	42	44	24	90	85	68
Q	300	500	200	300	400	500	400
PT	A	B	C	D	A	C	C

4. Experiments and Analysis

Experiments of numerical studies are carried out in this paper. The experiments are based on two stages in the hybrid flow shop. Stage 1 has two equipment and stage 2 has three equipment. There are 7 production orders with their attributes, as shown in Table I. According to our real-life concerns, we ignore the setup time due to the specific equipment features. Thus, processing time is the critical input variables in these experiments.

Table 2: Experiment Results

Approach	Sequence	$\Sigma Tardiness$	ΣCT
Priority-based	① ⑤ ③ ⑦ ④ ⑥ ②	87	32
Material-based	① ⑤ ③ ⑦ ⑥ ④ ②	94	24
SPT	① ⑤ ④ ③ ⑦ ⑥ ②	49	24
Proposed Model	① ④ ② ③ ⑦ ⑥ ⑤	2	32

A. Production Planning Level

The purpose of this experiment is to compare the proposed model and decisions based on some rules which are used in our collaborators. Two key factors are concerned. One is total tardiness and one is total time spent on

changeover of equipment tools. The results are shown in Table 2.

From Table 2, the results obtained from the proposed model are compared with three approaches used in the production department in the case company. These approaches are priority-based rule, material-based rule and shortest processing time (SPT) principle. Priority-based rule sequences the production order according to their weight/priority (ω_i). If the weight is equal, SPT will be used. Material-based rule groups the materials with same attributes and combines SPT principle. SPT sequences the production orders according to their processing times. Due date will be considered secondly under the situation of equal processing times.

Using four methods to solve the production planning problem, the sequenced results are listed in Table 2. Each sequence is evaluated by two key factors: total tardiness and time spent on changeover of equipment tools. The four methods are examined with the total tardiness 87, 94, 49 and 2 respectively as well as total time upon changeover of equipment tools are 32, 24, 24 and 32 (Here, a unit of time for equipment tool changeover is 8). Compared with the three approaches, the model proposed in this paper outperforms them in terms of total tardiness as well as sum of total tardiness and total time upon changeover of equipment tools.

Table 3: Jobs for Scheduling

J_i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
P	3	3	6	6	6	6	6	5	5	3	3	3	5	5	5	5	5	5
ω	1	1	5	5	5	2	2	4	4	1	1	1	4	4	4	2	2	2
d	8	8	42	42	42	44	44	24	24	90	90	90	85	85	85	68	68	68
Q	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
PT	A	A	B	B	B	C	C	D	D	A	A	A	C	C	C	C	C	C

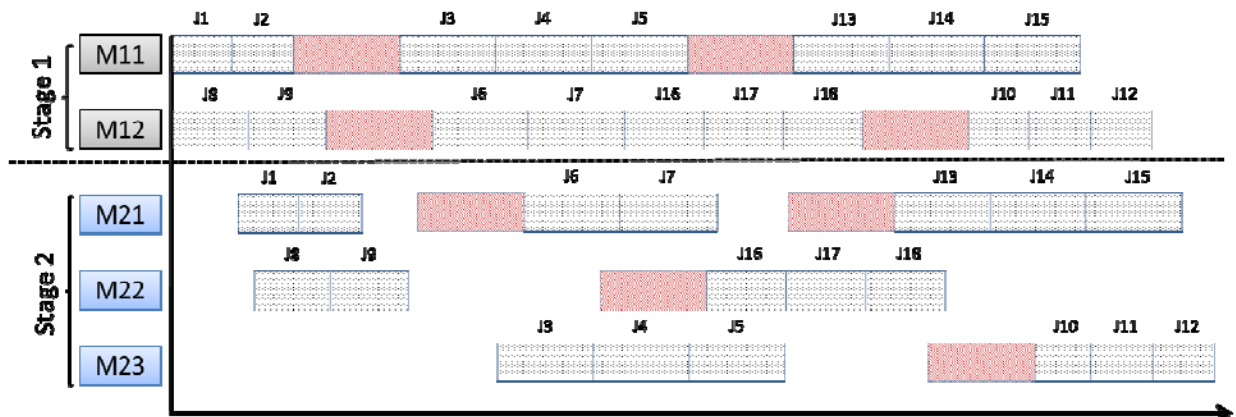


Figure 2: Simulation Results in Gantt Chart

B. Production Scheduling Level

Table 3 demonstrates the split jobs from the production orders listed in Table 1. There are 18 jobs each of which contains the standard quantity that is 180 pieces. After releasing from production planning, the jobs in the real-time job pool for 1st stage are sequenced as: ① ② ⑧ ⑨ ③ ④ ⑤ ⑥ ⑦ ⑩ ⑦ ⑬ ⑬ ⑭ ⑮ ⑩ ① ⑫. The objectives concerned in scheduling level are maximization of equipment utilization and makspan.

To this end, real-time job pool in stage 1 releases jobs to job pools for individual equipment given some dispatching rules like same materials grouped mechanism etc. Each equipment should process jobs as soon as possible so that next stage can get the jobs immediately. Based on the working mechanism, the model solution is shown in Figure 2 which indicates the optimal sequences that each equipment processes which job at what time in a Gantt Chart form.

In Figure 2, the red rectangle represents the time spent on equipment tool changeover when installing and uninstalling tools with different materials within jobs alternatively. The other type of rectangle represents the processing time of a job in a specific equipment. From Figure 2, the total time spent on the changeover is 64. At

the first stage, jobs are processed by two equipment after their grouping with several criteria. At the second stage, jobs finished at stage 1 enter the real-time job pool which assigns jobs to different machines.

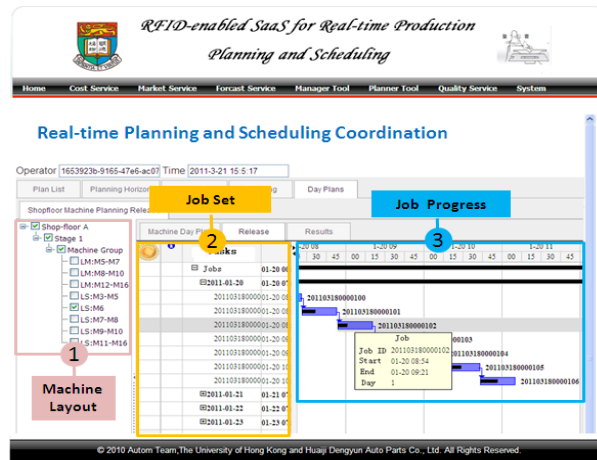


Figure 3: Coordination using a real-time Kanban

C. Coordination Using A Real-time Kanban

Planning and scheduling are coordinated through a real-time Kanban which integrates the real-time RFID execution data from manufacturing sites and upper decisions like plans and schedules. The coordination mechanism is based on three key elements: machine layout, jobs layout and jobs progresses.

- Machine layout uses a TreeGrid component to display the equipment structure in different manufacturing stages. It intends to facilitate planners and schedulers to review the jobs arrangements for different equipment groups/individual equipment.
- Jobs layout utilizes a TreeGrid component to organize the jobs from real-time job pools for a specific equipment or group, for example, in different working days or shifts. Jobs could be adjusted here manually by end-users given the real-time situations from manufacturing sites.
- Jobs progresses use Gantt Chart to show the fulfillment of a job at an equipment with certain materials. It enables decision makers (e.g. planners and schedulers) to real-time monitor the jobs. In case of disturbances, for instance, a delay occurs at a job, it gives warnings so that affected parties are able to immediately coordinate to adjust the plans/schedules so as to avoid production order delay.

Through the approach, the planning and scheduling achieve a real-time and coherent; likewise, the feasibility and practicality of plans and schedules are more reasonable. Furthermore, the collaboration within different manufacturing parties is enhanced to a level that is graphical and on-time.

5. Conclusion and Remarks

This paper introduces a real-time planning and scheduling model in a RFID-enabled manufacturing environment. This model is based on hybrid flowshop (HFS) and real-time job pools which aim to combine the theoretical and practical aspects seamlessly in the real-life applications. A numerical experiment study shows the feasibility and practicality of the potential implementation of this method. Experiments results report that the proposed model outperforms over the rule-based approaches that used in the case company.

Several aspects are significant in this paper. First of all, this paper sets up a model that considers the planning and scheduling decisions interactively within the RFID-enabled real-time planning and scheduling. RFID technology is used to identify various manufacturing resources that the model concerns about. Secondly, a real-time Kanban is adopted to coordinate the planning and scheduling level, thus, the gaps among planning, scheduling and execution are bridged. That means the decisions like plans and schedules could be real-timely reflected on manufacturing frontlines such as work-cell or equipment, while, the real-time statuses of frontline objects are fed back to the decision-making parties for supporting their further assessment. Thirdly, this proposed model concerns some practical elements which are paid critical attention in this case. Practical parties like planners and schedulers can easily understand and interpret.

Future researches will be carried out in three dimensions. First, the processing times or standard operation times (SOTs) are largely different given the individual operator's skill level, shifts, identical machines etc. Data mining approach should be used for discovering the more practical SOTs and their key impact factors. Second, after using the more practical SOTs, an improved planning and scheduling model should be established to

enhance the precision of plans and schedules. Third, the proposed model will be realized in a RFID-enabled advanced planning and scheduling system which is able to assist small and medium-sized manufacturing companies to improve their production planning and scheduling in the near future.

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