RAPSHELL FOR RFID-ENABLED REAL-TIME SHOPFLOOR PRODUCTION PLANNING, SCHEDULING AND EXECUTION

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ABSTRACT

In typical enterprises that adopted RFID technology, different manufacturing parties are facing challenges on collaboratively making decisions such as conflicting objectives as well as gaps between high-synchronized information flow and unstandardized decision-making procedures. In order to facilitate different parties' decision-making behaviors such as planning, scheduling and execution bodies, this paper introduces an RFID-enabled real-time advanced planning and scheduling shell (RAPShell in short) to enable real-time coordinate with each other. In RAPShell, customer orders are converted into production order in planning level, then scheduled in scheduling level and finally carried out in execution level. It uses RFID technology in execution level to real-time capture the production data, which will be fed back to scheduling level for real-time rescheduling and finally to meet the constrains set in planning level. That forms a closed-loop within the entire manufacturing environment so as to improve the efficiency and effectiveness of decision-making. A case study from a real-life demonstration shows how RAPShell can help different end-users such as planners, schedulers, machine group leaders and machine operators to ease their activities.

1 INTRODUCTION

Real-time planning and scheduling involves the allocation of resources (e.g. labours, machines and materials) to tasks in a way that certain performance requirements are met [1, 2]. This topic has been probably the most widely researched area due to the belief that the basic problem in real-time systems is to ensure that the tasks have to meet the time constraints. Given the time constraints, examples of such systems are operating systems, command and control systems as well as flight or space shuttle avionics systems since these fields are highly sensitive to time variety and belong to advanced technology applications [3]. These applications are based on advanced technologies and algorithms for scheduling. Thus, these companies benefit from them in terms of high efficiency, low cost and splendid reliable.

These benefits have attracted attention and interests from small and medium-sized manufacturing companies. They are contemplating the real-time planning and scheduling system in outsourcing and supply chain management (SCM), especially in production control and management [4]. However, highly stochastic customer orders created practical hurdles for these companies to implement this system. Such stochastic behavior generates great myriad of uncertainties and disturbances such as emergency orders and engineering changes which affect, corrupt and deviate normal plans and schedules [5]. The uncertainties and disturbances further cause snow-ball effects such as delay on customer orders, material delivery errors and high level of Work-In-Progress (WIP) inventory.

In recent years, academics and practitioners have adopted advanced planning and scheduling (APS) and lean manufacturing such as just-in-time (JIT) principle to achieve real-time production. However, they become fragile in dynamic manufacturing environment because production control, in practice, are highly uncertain, varied and conflicted objectives [1]. A solution is needed to enhance their ability of balancing the conflicts, controlling the release of jobs to manufacturing shopfloors, ensuring the required material on a time basis and identifying various uncertainties [6]. The solution must be supported by real-time manufacturing shopfloor data that most of companies do not have suitable collection mechanism in place.

In order to facilitate real-time data collection, AUTO-ID technology has been widely used in SCM, warehouse management (WM) and production control [7-11]. Kohn firstly used RFID to collect information for supporting real-time enterprise planning, scheduling and controlling processes [12]. For example, the real-time inventory data can be obtained via RFID technology by attaching RFID tags on items and reading these tags via RFID reader. The use of RFID technology increases the efficiency and speed on inventory control, logistics operations and the associated transactions. However, RFID applications on real-time manufacturing control (e.g. planning and scheduling on manufacturing shopfloor) are scarcely reported.

Within the RFID-enabled enterprises, different manufacturing parties are facing challenges when collaboratively making decisions. This is because they are always confronted with conflicting objectives as well as the incoherency of high-synchronized information flow and unstandardized decision-making procedures. This paper introduces a RFID-enabled real-time advanced planning and scheduling shell (RAPShell) to enhance the coordination of various manufacturing parties' decision-making activities.

Several research questions are concerned in this paper. First of all, what operation principle can be applied for coordinating the planning, scheduling and execution activities in order to improve the decision-making efficiency and effectiveness? Secondly, what mechanisms can be used for standardizing the users' behaviors in planning, scheduling and execution levels?

In order to address the above questions, this paper adopts hierarchical production planning (HPP) and RFID technology for enhancing the information collection and sharing to coordinate the decision-making activities of different manufacturing parties. Additionally, a generic information system framework is proposed with easy-to-deploy and simple-to-use characteristics to standardize the decision making operations.

The rest of this paper is organized as follows. Section 2 presents the overview of RAPSHell and its key services. Section 3 reports on a case study which demonstrates how different users operate the RAPSHell and its services to fulfill their daily operations. Section 4 concludes this paper by giving our main contributions as well as future work.

2 RFID-ENABLED REAL-TIME ADVANCED PLANNING AND SCHEDULING SHELL

This section mainly discusses the RFID-enabled real-time advanced planning and scheduling shell (RAPSHell) in terms of framework overview, key services and practical issues considered within the real-life situations.

2.1 Overview of RAPShell

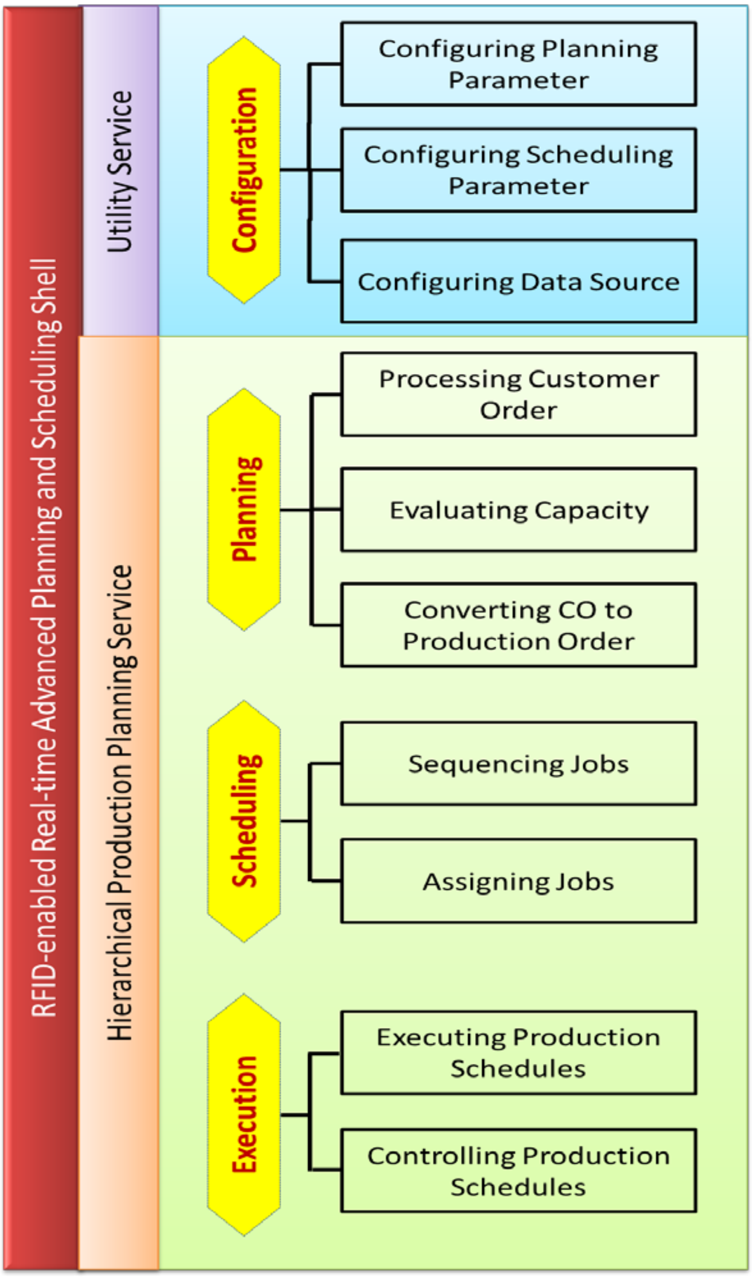

Figure 1: Overview of RAPSHell

Figure 1 shows the overview of RAPSHell. It mainly contains two parts: utility service and HPP service. Utility service is responsible for enabling software engineers to define and configure RAPSHell in terms of user roles and types, database connections, system layouts as well as services' parameters. A set of explorers are designed for these functionalities. They assistant other entities such as a third-party service providers to sustain the reliable functions and system updating.

HPP service adopts the hierarchy production principle including planning, scheduling and execution each of which are designed and developed as individual services to facilitate different manufacturing parties' decision-making activities. It includes a rich set of explorers for this purpose. Three key services are planning service, scheduling service and execution service that will be reported in the following section in detail.

2.2 Key Services

2.2.1 Planning Service

The purpose of planning service is to incorporate a multiplicity of manufacturing elements such as workers, machines and materials to satisfy the delivery times of various customer orders and minimize the production cycles and costs. This service enables planners to process customer orders and work out the optimized plans through a standardized fashion. The process is divided into three phases: processing customer orders, evaluating capacity and making production plans.

Processing customer orders includes several vital tasks. First of all, the evaluation horizon is defined. Secondly, a set of customer orders is imported through converting diversified data sources (e.g. Excel files, XML documents and databases) into a standard format. The set is evaluated and turned into production orders under the predefined horizon. Ultimately, priority of each production order is initiated according to various criteria like customer priorities, order due-date etc.

Evaluating capacity compromises three tasks. First, order priorities are evaluated by a mathematical model. Let $\mathrm{P_i}$ denotes the order priority which subjects to $1 \leq P_i \leq 5, 1 \leq i \leq n$. That means there are five grades of priority with smaller value indicates higher priority. Then, the evaluated priority P' is determined by:

$$P_i' = \begin{cases} 1 \; if \; P_i = 1 \\ \alpha_1 P_1 + \alpha_2 P_2 + \cdots + \alpha_k P_k \; if \; P_i \neq 1, k \in N \end{cases} \quad \textbf{(1)}$$

Where $\mathrm{P_i} = 1$ denotes the preference order (with highest priority) that must be processed as soon as possible. $\mathrm{P_k}$ represents the determinative element with its weight α_k which subjects to $\alpha_1 + \alpha_2 + \cdots + \alpha_k = 1$. Second, machine capacity is evaluated by a model which aims to estimate the overlap between the machine capacity MC_i and the requirements from the production orders MCR. This model is expressed as follows.

$$MC_i \propto MCR \quad \textbf{(2)}$$

Where, MC_i subjects to $MC_i^{max} - OMC_i \leq MC_i \leq MC_i^{max}$. That means the value of MC_i is between the maximum machine capacity MC_i^{max} and the difference of MC_i^{max} and occupied machine capacity OMC_i. $\propto$ is an operation to figure out the overlap. $\mathrm{MCP} = \sum_{j=1}^{n} O_j^{rc}$ where O_j^{rc} implies the required machine capacity from an order. Third, the evaluated consequences could be reviewed and then finalized for the further processing.

Making production plans includes three steps. Production orders are firstly sequenced and listed. The results can be manually re-arranged and modified if necessary. Secondly, specific rules and objective functions developed as individual web services are chosen for various situations such as minimizing makespan or WIP inventory etc. Finally, the optimized output is named as day-to-day plans determining which orders will be addressed at what time.

2.2.2 Scheduling Service

Scheduling service aims at determining a production facility what to make, with which worker at what time, maximizing the efficiency of the operations on the worksite. It enables schedulers to convert the scheduling processes to a real-time and graphical fashion so that the disturbances could be handled timely. This service involves two phases. They are sequencing and assigning jobs.

Sequencing jobs uses a real-time job pool and hybrid flowshop model to facilitate the scheduling operations in a RFID-enabled real-time decision-making ambience [13]. Sequencing jobs consist of two stages. At the first stage, the objective is to maximize the machine utilization. The sequencing criteria are based on job's priorities and some rules like grouping method according to material property, cascaded jobs standard etc. At the intermediate stage, the objective is to minimize the tardiness and earliness of jobs. Several dispatching rules are used for these purposes such as FIFO (First in First out), SPTF (Shortest Processing Time First) etc.

Assigning jobs refers to the manual interventions such as the adjustment of the sequences in a job pool. This may occurs under some specific situations like emergency orders' arrival, machine break down etc. As a result, a friendly editing principle is necessary. Here, we use drag-and-drop approach to achieve this principle. That is significant for the machines which can deal with multiple jobs.

Several practical issues are concerned in production scheduling service. First of all, the scheduling decision may be postponed. For example, the high variability of setup time, processing time and unpredicted disturbances disrupt the decisions which determine which operator does which job at what time in what sequence. By using the concept of real-time job pool, machine operator always picks up the job with high priority [13, 14]. Thus, the scheduling problem is simplified to sequence various jobs in the pool. Secondly, production scheduling involves in large number of manufacturing units like shopfloors, assembly lines and work stations. Collaborative decision-making is greatly important. Real-time data collection is not adequate in practice. Here, we use a Gantt Chart to visualize the real-time RFID-captured manufacturing data. The Gantt Chart combines the real-time information of machines, workers, materials and jobs together so as to provide a holistic view of the entire manufacturing sites. Any disturbances could be captured and reflected to the chart immediately. Therefore, the involved manufacturing parties are able to work out the corresponding decisions collaboratively.

2.2.3 Execution Service

Execution service aims to coincide the planned and scheduled jobs with their executions as well as carrying out the supervision of coordinated production activities in an efficient manner. It enables frontline workers such as machine operators, logistics operators to report critical information like machine statues, jobs progresses and uncertain disturbances etc. The information supports different decision makers (e.g. planners, schedulers, even senior managers) to make precise and practical resolutions during the production processes.

RFID technology plays an important role in this service. RFID devices are deployed to various manufacturing resources physically such as machines and materials, to convert them into smart objects (SOs). After that, they are able to detect, communicate and interact with each other through wireless connections. Two types of SOs are created. First is active SOs which are equipped by RFID readers. The other is passive SOs that are attached by RFID tags. They are managed by a RFID-Gateway.

RFID-Gateway acts as a host that connects all the SOs. It provides a set of services to manage the SOs' operations and activities, aiming at collecting the real-time information and passing it to upper-level entities according to the predefined workflow. Two types of RFID-Gateways are involved. First is work station gateway which is responsible for accessing jobs from pools by machine operators through patting their staff cards. Second is shopfloor gateway which is responsible for defining, configuring and executing corresponding agents through a rich set of tools and services.

Execution service follows several procedures. First of all, machine operators pat their staff cards on work station gateway to record the availability. This action also uniquely binds machines and their operators. Secondly, jobs with high priorities are released to machines immediately together with some key information such as job instructions, technical figures etc. The information will be displayed on the gateway screen. Thirdly, logistics operators check the logistics tasks through gateways and move the materials to machine buffers when the jobs are released. Fourthly, after finishing a job, machine operators pat their staff cards again to mark the job finish and send a message to the inspectors for quality checking. The job enters into the pool at next stage after the inspection. After that, logistics operators will deliver the materials to next process. Meanwhile, next job will be released to the machine operator immediately.

3 CASE STUDY

The case study comes from a real-life company that specializes in manufacturing various engine valves. The company is Huaiji Dengyun Auto Parts (Holding) CO., LTD. (Huaiji for short). It has used RFID technology for supporting its shopfloor production since 2005. Significant improvements have been obtained in terms of real-time data collection, visualized WIP traceability as well as rationalized production operations [14]. However, it is facing coordination challenges when making production decisions.

3.1 Coordination Challenges

The coordination challenges come from three dimensions which involves in production department, manufacturing shopfloors as well as frontline work-cells.

First of all, planners in the production department convert the customer orders into production plans which will determine when the products are able to be manufactured so as to meet the delivery time. The planned results are easily interrupted by any disturbances such as machine break down or emergency orders. Although the real-time manufacturing data are captured in frontline sites and feedback to planning level, senior management parties like production manager or planners are reluctant to change it frequently. This is because it is high time-costing and there is no standard procedure to support their adjustment behaviours. That means what they do is based on their past experiences. In addition, the plans are released to the scheduling level according to “the sooner, the better” principle which means the scheduling party getting the plans immediately and suddenly after plans’ release operation without considering the current situations on manufacturing shopfloors. That makes the planners are busy to dealing with re-planning operations which are time consuming and labour intensive.

Secondly, schedulers on manufacturing shopfloors (shopfloor supervisors act as schedulers in this case), get the random released plans and then converted into manufacturing jobs. Since Huaiji adopts batch production with a very wide product variety of variable batches, scheduled results are usually disturbed by the released plans or some emergency orders. Therefore, shopfloor supervisors are busy in cooperating with planners from production department and machine operators from frontline manufacturing sites to re-schedule and change the plans frequently. Fire-fighting situation usually occurs in the company. Planners usually criticize the others are not able to fulfil the plans strictly and schedulers frequently complain the dynamics from released orders and manufacturing sites. The poor collaboration leads to delay of customer orders, weaken harmony in manufacturing units as well as downturn of various workers.

Finally, machine operators from frontline work-cells are busy in doing no-end-in-sight jobs every day and operating data collection devices like RFID readers and tags to capture the real-time manufacturing information. Unfortunately, they are usually confronted with unpredictable disturbances such as machine break down, jobs' adjustments like cancellation and re-arrangement, as well as emergency jobs. These disturbances, on one hand, occur suddenly without any clues, which may cause serious results such as delay of product delivery. On the other hand, the disturbances greatly affect the mood swing of different workers without a suitable collaboration mechanism. It is a high cost to address the sequelae that are triggered by unsuitable treatment of these disturbances.

The main cause of the above challenges is lack of a decent platform which can coordinate different manufacturing parties like production planning, scheduling and execution through a standardized approach and guide different users to make decisions. To this end, this company contemplates to deploy RAPShell to its manufacturing parties.

3.2 Customization of RAPSHell in Huaiji

The customization of RAPShell includes several steps. The first step is the initiation of system network. RAPShell is a web-based system following a standardized service-oriented architecture (SOA) which is based on Internet. The second step is the server-side deployment. This deployment includes website address, source code implementation and so on. The third step is the configuration of system parameters such as services' properties, database connection etc. That ensures large number of end-users are able to access corresponding services accurately. The final step is the client-side personalization. It contains the customized layout, system style etc.

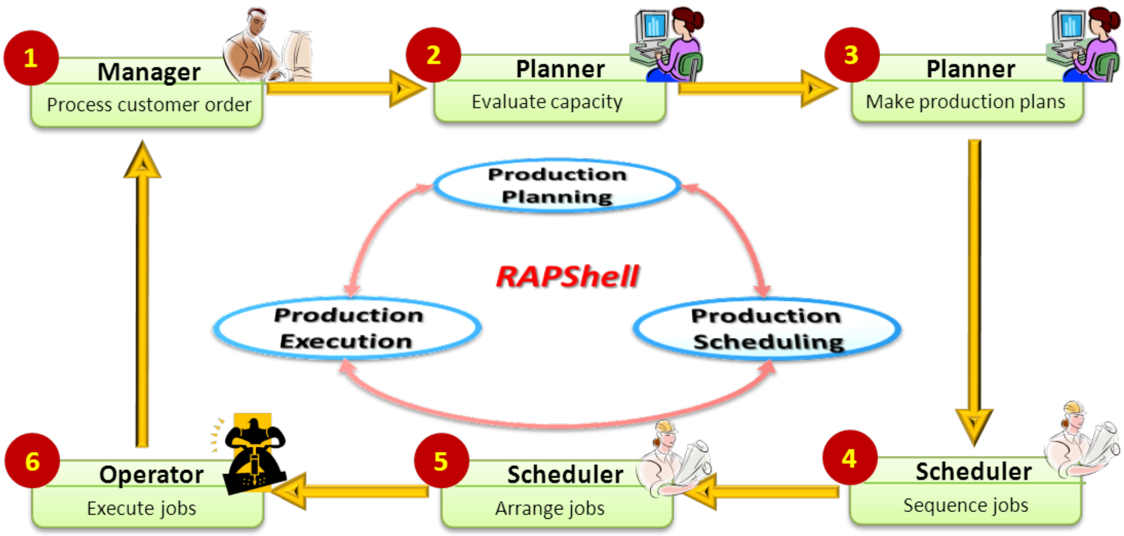

Figure 2: Reengineered Production Decision-Making Processes with RAPShell

3.3 Reengineered Production Decision-making Processes

After the customized deployment of RAPShell, different users are able to use the services provided by this system to facilitate their daily operations. With the assistance of RAPShell, the production decision processes are reengineered and rationalized. Figure 2 reports on the reengineered processes. Typical users' operations in the case company like manager from production department, planner from production department, scheduler from manufacturing shopfloor as well as operator from work-cell are facilitated by a rich set of explorers in RAPShell. The processes include six steps which are explained as follows.

Step 1: Manager from production department opens "Customer Order Processing Explorer" to convert the customer orders into production orders. The manager initials the priorities of each order according to some criteria such as customer importance, earliest due date and FIFO.

Step 2: Planner from production department uses “Capacity Evaluation Explorer” to carry out the operations. Firstly, the planner utilizes the reprioritized model which is designed and developed as an individual web service to evaluate the production order priorities. Secondly, the planner estimates the overlap between the current machine capacity which is calculated by the RFID-enabled real-time information from manufacturing shopfloor and the order requirements through calling a special service that is based on the evaluation model. Finally, the planner reviews the evaluated results which are sequenced specifically.

Step 3: Planner opens up “Production Planning Explorer” to make plans. The planner firstly selects the objective functions that are developed as web services. The planner can choose different objectives based on different situations such as in peak season and off-season. Secondly, the planner is able to adjust the evaluated results manually in some cases such as changes of customer orders. Ultimately, the planner makes and finalizes the plans which will be further processed in scheduling stage.

Step 4: Scheduler from manufacturing shopfloor uses “Production Scheduling Explorer” to sequence the planned results in the real-time job pool and to select an objective function to schedule the jobs. The schedules are organized by a Gantt Chart which implies which job is processed at what time by which machine group and how long each job takes. The scheduled jobs are fed back to planning level real-timely. If there are some adjustments, planner is able to inform scheduler to do as soon as possible.

Step 5: If the planner confirmed the scheduled jobs in Gantt Chart, scheduler uses “Production Scheduling Explorer” to arrange the jobs manually to different machines. Drag-and-drop editing principle is adopted, thus, scheduler can distribute several jobs to specific machines that are able to process multiple jobs.

Step 6: Machine operator from frontline work-cell reads his staff card on RFID-Gateway to get the jobs with high priorities from real-time job pool. The progresses are real-timely feedback to scheduling and planning level by means of “Production Execution and Control Explorer” which enables different manufacturing parties to supervise the current situations through different views like monitoring of machines, workers, materials, jobs and disturbances. These views help them in making corresponding decisions collaboratively.

3.4 Improvements from Qualitative Aspects

RAPShell has been implemented in Huaiji around six months. Qualitative improvements are obtained and categorized into the following facets.

- Enhanced coordination of decision-making parties. RAPShell integrates production planning, scheduling as well as execution & control seamlessly through real-time sharing and feedback of the RFID-enabled manufacturing data among different parties. Therefore, they are able to collaboratively work out production decisions which are based on separate and individual considerations before the system implementation. The collaborative mechanism not only enhances the coordination of heterogeneous functional parties, but also boosts various entities in a manufacturing party.
- Standardized decision-making procedures. Different end-users’ decision-making procedures are standardized by RAPShell which provides a rich set of services for facilitating their operations and behaviours. These services are designed and developed as individual explorers that assist large number of users to fulfil the production planning, scheduling, execution and control operations.
- Improved workers’ spirit and manufacturing efficiency. The above two improvements bring amplifier effect that the workers’ spirit and manufacturing efficiency has been greatly lifted. For workers’ spirit, RAPShell coordinates different parties to figure out suitable solutions for various situations. Accordingly, they have the same objectives and are able to think, work and play creatively and efficiently with high spirit, high

responsibility and high harmony. For manufacturing efficiency, the coordinated decisions can be understood and reported to different related parties immediately. They are able to carry out the decisions as soon as possible through RAPShell facilities such as explorers, RFID-Gateways etc.

4 CONCLUSION

This paper introduces a RFID-enabled real-time advanced planning and scheduling shell (RAPShell) to help small and medium-sized enterprises in making production decisions coordinately. RAPShell uses SOA model for designing and developing its modules that are based on Internet/Intranet. Different users can easily access this system to ease their daily operations in terms of production planning, scheduling, execution and control.

There are several significant contributions in RAPShell. Firstly, RAPShell is a web-based shell which can be easily deployed, simply used and flexibly accessed. That means RAPShell provides a platform so that any new functions could be developed as web services which are able to add into the shell through simple configurations. In addition, RAPShell can be customized given the practical situations in different applications. Secondly, RAPShell uses software as a service (SaaS) principle that services and associated data are centrally hosted on a cloud. Users open up a web browser to access this system. Therefore, RAPShell is designed as a service with its modules developed as services which are realized by web services. Finally, RAPShell adopts hierarchical production decision-making integration mechanism which combines planning, scheduling, execution and control by using RFID-enabled real-time data sharing among different parties. By using this methodology, the real-time production data are captured for guiding the decision-making parties to work out corresponding solutions, while, frontline workers can get the solutions immediately. Thus, a closed-loop decision play is achieved.

Future research directions include two parts. Firstly, the standards for information management like ISA-95 will be used for integrating the enterprise information systems (EISs) and RAPShell. Secondly, the RFID-enabled production data from shopfloors carry significant and implicit information and manufacturing knowledge. A data mining model is studied for discovery the useful knowledge so as to support precise decision-makings like production planning and scheduling within RFID-enabled real-time manufacturing environments.

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