Chapter 9
Real-Time Work-in-Progress Management for Ubiquitous Manufacturing Environment

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Abstract Recent developments in wireless technologies have created opportunities for developing next-generation manufacturing systems (NGMS) with real-time traceability, visibility and interoperability in shop-floor planning, execution and control. This chapter proposes a referenced infrastructure of Ubiquitous Manufacturing (UM). Under this infrastructure, a Smart Gateway and a real-time work-in-progress management system (WIPMS) based on smart objects such as RFID/Auto-ID devices and web service technologies are designed to manage and control the real-time materials flow and information flow to improve the optimal planning and control of the entire shop-floor. During manufacturing execution stage, they can provide operators and supervisors with real-time status and information of current manufacturing environment. It follows a simple but effective principle: what you see is what you do and what you do is what you see. Production disturbances could thus be detected and fed back to decision makers for implementing closed-loop shop-floor control. For manufacturing information sharing and integration, a work-in-progress markup language (wipML) is used to establish the information model and schemas of WIP based on some important standards such as ISA 95 and B2MML. Then, the real-time manufacturing information can

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be effectively encapsulated, shared and exchanged between Smart Gateways, WIPA and heterogeneous enterprise information systems (EISs). Finally, the presented framework is demonstrated through a near real-life simplified shop-floor that consists of typical manufacturing objects.

Abbreviations

AMT	Advanced Manufacturing Technology
AUTOM	Manufacturing Powered by Auto-ID Technologies
AWFM	Agent-based Workflow Management
B2MML	Business-to-Manufacturing Mark-up Language
BOM	Bill of Materials
ceXML	Critical event Extensible Markup Language
EISs	Enterprise Information Systems
FMS	Flexible Manufacturing System
HF	High Frequency
ISA	Industry Standard Architecture
NGMS	Next-generation Manufacturing Systems
PRD	Pearl River Delta
RFID	Radio Frequency Identification
SOA	Service-oriented Architecture
SOMS	Smart Object Management System
SOs	Smart Objects
soUDDI	Smart objects Universal Description, Discovery and Integration
UHF	Ultra-High Frequency
UM	Ubiquitous Manufacturing
WBF	World Batch Forum
WfMC	Workflow Management Coalition
WIPA	Work-in-progress Agent
wipML	Work-in-progress Markup Language
WIPMS	Work-in-progress Management System
SQL	Standard Query Language

9.1 Introduction

Manufacturing is the battlefield of global competition. In the past ten years, typical challenges that manufacturing enterprises are facing in the dynamic global business environment are shortened products lifecycle, fluctuated demands and rapid upgrading of manufacturing technologies. To strive for their competitiveness, companies have to adapt advanced technologies and management approaches (both software and hardware). Recently, rapid developments in wireless sensors, communication and information network technologies (e.g. radio frequency identification-RFID or Auto-ID, Bluetooth, Wi-Fi, GSM, and infrared) have nurtured the emergence of Ubiquitous Manufacturing (UM) [1, 2] as core Advanced Manufacturing Technology (AMT) in next-generation manufacturing systems (NGMS). A UM system is based on wireless sensor network that facilitates the automatic collection and real-time processing of field data in manufacturing processes. In this way, the error-prone, tedious manual data collection activities are reduced or even eliminated [3].

UM provides a networked manufacturing environment free from excessive and difficult wiring efforts in manufacturing workshops [4]. In UM, real-time visibility and interoperability have been considered core characteristics [5] that close the loop of production planning and control for adaptive decision making. A new paradigm, called UbiDM: Design and Manufacture via Ubiquitous Computing Technology [6], has been proposed for the design and manufacturing of a product by using ubiquitous computing technology. The importance of the UM has also been widely identified for strategic research and development in industrialized European Union, North Americas, and Japan where manufacturing is widely considered as one of the major means of creating the national wealth.

Despite significant progress achieved by research and practitioner communities, major challenges still exist in applying Auto-ID/RFID technologies to the real-life manufacturing shop floors. For example, in a real-life shop floor, different types of Auto-ID devices may be needed due to different production requirements and working conditions. Usually, staff members usually use High Frequency (HF) tags, single items of materials are attached with bar-codes by their supplies, while pallets are often attached with Ultra-High Frequency (UHF) tags because they are cheaper and could be reused, etc. Because different Auto-ID devices entail different software drivers and invoking standards/protocols provided by their suppliers, as a result, it is both labor and skill intensive to set up and manage heterogeneous RFID devices for different industrial applications without a standardized model. Moreover, operation changes resulted from order changes is a commonplace in real-life manufacturing shop floors. Therefore, an easy-to-use configuration mechanism is necessary for defining the data capturing activities required by different manufacturing companies. Our recent investigation within several manufacturing enterprises in Pearl River Delta (PRD) of China has revealed several research questions before a breakthrough can be achieved in real-time UM. They are summarized as follows:

1. How to build up a platform to integrate and manage multiple types of Auto-ID devices to capture complex real-time information from manufacturing execution?

2. How to use a standard model to wrap the multiple types of RFID devices so that they can work in a "plug and play" manner and be used without specialist knowledge?

3. How to rapidly and flexibly define the flow of real-time data collection, which is the allocation (e.g. sequences and times) of appropriate RFID devices/ Agents to collect data from a dynamically changed production process?

4. How to facilitate the real-time WIP management through smart objects enabled UM infrastructure under the service-oriented architecture?

5. How to share and transmit the static and dynamic shop-floor manufacturing information among heterogeneous systems by using the standard services?

6. How to apply the current manufacturing standards to Work-in-progress Management System (WIPMS) so that it can be easily integrated with other EISs?

7. How to design and develop the visibility explorers based on the timely shop-floor information for different users to enhance their productivity and efficiency?

In order to address the above questions, in this chapter, a referenced UM infrastructure, the overall architectures of Smart Gateway and WIPMS, and their core technologies are described based on some advanced technologies and standard such as RFID, agents, web service, the ISA 95 and B2MML standard. It aims to eliminate the information gap between shop floor management system and representative execution units, and provide a new paradigm for the development of RFID-enabled UM solutions and corresponding WIP management. It is stated that the overall infrastructure and corresponding core technologies of this chapter have used and integrated the relevant research contributions of our previous works reported in a series of international journal papers [2, 7, 8].

The rest of the chapter is organized as follows. Section 2 reviews the literature related to this research. Section 3 outlines an overall infrastructure of smart objects enabled real-time ubiquitous manufacturing. Section 4 describes the overall architecture and core technologies of Smart Gateway. Section 5 discusses the overall architecture and core technologies of WIPMS in shop floor environment. Section 6 reports a case study on the implementation of the proposed WIPM framework for a typical manufacturing shop floor. Conclusions and future works are given in Sect. 7.

9.2 Literature Review

At least four streams of related works are relevant to this research. They are real-time manufacturing capturing, agent technologies, workflow management, as well as manufacturing information sharing and integration.

1. Real-time manufacturing capturing

Auto-ID technologies such as RFID have been widely applied to automatically capture real-time data [9]. Early RFID manufacturing applications have been briefly quoted by Brewer et al. [10]. Johnson [11] presents a RFID application in a car production line. Chappell et al. [12] provide a general overview on how Auto ID technology can be applied in manufacturing. Huang et al. [13] have implemented RFID technologies to capture the real-time information of workers, machines and materials of fixed-position and assembly line. Zhang et al. [14] have designed and developed a RFID-based smart Kanban system for shop-floor WIP management. Alejandro et al. [15] have developed an innovative and ecological packaging and transport unit called MT for the grocery supply chain based on active RFID tags.

2. Agent technology

In order to enhance the flexibility of shop-floor management, agent technology has been introduced in manufacturing applications. Krothapalli [16] proposes an agent based concurrent design environment to integrate design, manufacturing and shop-floor control activities. By combining RFID with intelligent agents, a location-sensing system [17] and an intelligent guided view system [18] have been developed. Jia et al. [19] proposed an architecture where many facilitator agents coordinate the activities of manufacturing resources in a parallel manner. Jiao et al. [20] applied the Multi-Agent System (MAS) paradigm for collaborative negotiation in a global manufacturing supply chain network. Besides, in various kinds of applications such as distributed resource allocation [21], online task coordination [22], supply chain negotiation [23], the agent-based approach has played an important role to achieve outstanding performance with agility.

3. Workflow management

Workflow management is a diverse and rich technology which has been applied in ever increasing industries. Hollingsworth [24] defines that a workflow process is a coordinated (parallel and/or serial) set of process activities that are connected in order to achieve a common business goal. Lazcano et al. [25] use workflow technology to manage complex processes in e-commerce and virtual enterprises. Montaldo [26] applies workflow management system to enhance business performance for small-medium enterprise. Tan et al. [27] adopts a novel dynamic workflow model-based fragmentation algorithm to execute the distributed processes. Lin et al. [28] propose a compound workflow model (CWM) is to provide graphic presentation of the production process. Zhang et al. [29] establish a distributed workflow management model to define, configure and execute the different manufacturing processes.

4. Manufacturing information sharing and integration

In real-life manufacturing environment, different enterprises usually use the different software packages. Difficulties of information integration may arise when information is exchanged among heterogeneous application systems. Therefore, standard models and schemas of manufacturing information play important roles in information sharing and integration of heterogeneous enterprise applications, not only at business or at manufacturing levels but also inside a single enterprise or between networked enterprises. Siemens Energy & Automation, Inc. [30] has developed an interface to achieve seamless connections between ERP and process control systems. Standard ISA95 [31] has been developed to provide standard models and terminology for the design and operation of batch control systems. Today, the availability of Web-based XML communications successfully bridges the gaps between heterogeneous EISs. Business-to-Manufacturing Mark-up Language (B2MML) [32] standard developed by World Batch Forum (WBF) specifies accepted definitions and data formats for information exchange between different EISs.

9.3 Overview of Real-Time Ubiquitous Manufacturing

This section presents a conceptual infrastructure for ubiquitous AUTOM (Manufacturing Powered by Auto-ID Technologies), as summarized in Fig. 9.1. It helps defining vertical and lateral manufacturing visibility and interoperability.

The aim of the proposed UM infrastructure is to apply Auto-ID technologies and develop an easy-to-deploy and simple-to-use real-time information infrastructure for manufacturing enterprises to achieve seamless dual-way connectivity and interoperability between heterogeneous EISs, shop floor and production line/workstations. According to the manufacturing hierarchy, the proposed real-time UM infrastructure includes three core components, namely smart objects, gateway and shop-floor management.

Smart Objects (SOs) are physical manufacturing resources that are made "smart" by equipping them with Auto-ID devices (i.e., RFID devices). Fox example, those with RFID readers are called active SOs (e.g. work stations and forklifts) while those with RFID tags are called passive SOs (e.g., tagged materials, pallets etc.). SOs interact with each other or Smart Gateway via wired and/or wireless connections and thus create an intelligent ambience in shop floor.

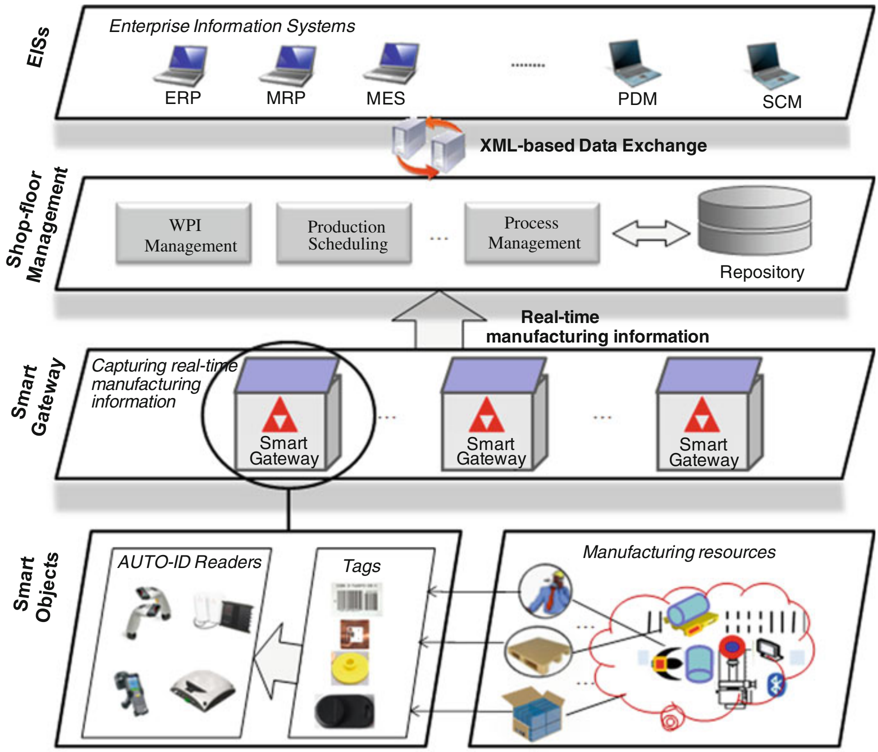

Fig. 9.1 A referenced infrastructure for ubiquitous manufacturing

In addition, taking advantages of its corresponding intelligent agent, SOs possess specified logics, processing ability and thus are able to sense, reason, and interact in the intelligent ambience.

Smart Gateway acts as a server to host and connect all SOs of the concerned production line or work-cell or work station, and also provides a suite of software applications (Agents and AWFM: Agents Based Workflow Management Framework) for managing their operations and activities. Smart Gateway captures real-time manufacturing information and passes it to upper-level applications or information systems according to a predefined workflow to enable appropriate real-time manufacturing process. From software perspective, a Smart Gateway is essentially an agent-based smart object management system (SOMS) [7] which defines, configures and executes the corresponding agents of SOs through services tools. From the hardware perspective, a Smart Gateway is like a hardware hub, which allows different type of connections (i.e. Bluetooth, TCP/IP, and USB etc.) to connect various types of SOs.

Shop-floor Management is at the center of the overall infrastructure. Its purpose is to provide a two-way information channel between shop floor and enterprise applications. From operations to enterprise decisions, it collects real-time information (e.g. real-time work-in-progress information) from the associated Smart Gateways and converts the information into standard formats to be directly used by enterprise information systems (EISs). From decisions to operations, on the other hand, it can receive enterprise's decisions, such as production planning and scheduling, from EISs and translate them into production orders or tasks that can be readily used by shop-floor operators or devices. A series of modules such as WIP management, production scheduling, internal logistics scheduling, process management, performance analysis etc. are developed and integrated in shop-floor management to provide service tools for real-time information exchanging between EISs and Smart Gateways.

In this chapter, the overall architecture and core technologies of the Smart Gateway and real-time WIPMS in a ubiquitous manufacturing environment will be described.

9.4 Smart Gateway

9.4.1 Architecture of Smart Gateway

Smart Gateway is an innovative platform that centrally connects and manages the multiple types of SOs necessary for capturing real-time manufacturing data. It has two unique characteristics. The first is "Plug and Play" scalability. SOs can be plugged in or removed from the Smart Gateway without stopping their functions for reconfiguration. The second is "reconfigurable", which means SOs can be easily configured for different processes with different real-time information capturing requirements.

The overall architecture of Smart Gateway can be seen in Fig. 9.2. It consists of three main components, namely smart objects and wrapping agents, smart object UDDI, Agent-based workflow management and real-time visibility explorer.

1. Smart objects and wrapping agents

For better managing the heterogeneous SOs, agent technologies are used to wrap different SOs as standard web services using the uniform service-oriented architecture (SOA) so that SOs are deployed in a "Plug and Play" fashion at Smart Gateway. It is otherwise very complex to configure various SOs with different communication interfaces in real-life manufacturing environment (e.g. HF reader, UHF reader, etc.).

2. smart objects Universal Description, Discovery and Integration (soUDDI)

It serves as a platform-independent framework for describing and discovering the services of smart object agents over the Internet. On the one hand, it can be used to register and publish standard web services of agents [33]. On the other hand, the real-time manufacturing applications can be implemented through binding and invoking the real-time data capturing services of the relevant agents in soUDDI.

3. Agent-based workflow management

Different products are manufactured with different production processes. Accordingly, same smart objects may play different roles in different production processes. In order to facilitate the configuration of smart objects in different manufacturing processes, a workflow management mechanism is considered as a core technology in Smart Gateway to define, configure and execute different processes.

9.4.2 *Core Technologies of Smart Gateway*

9.4.2.1 Service-Oriented Agent

Agent concept is adopted for wrapping all types of smart objects connected to the Smart Gateway as "plug and play" objects. The agent is smart because it can perceive the dynamic changes of manufacturing environment and reflect the

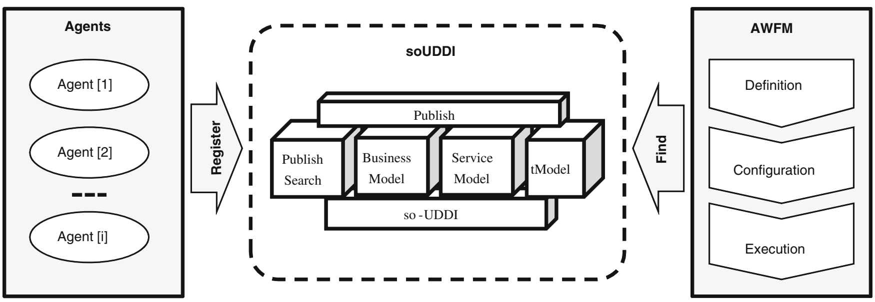

Fig. 9.2 Architecture of agent-based smart gateway

changes to Smart Gateway. For example, when an operator with a card (HF Tag) comes to one workstation that placed a Smart Gateway, the corresponding agent of a HF reader can capture the data of the operator card and translate it into meaningful manufacturing information. Then, the agent knows which operator has arrived at which workstation at which time etc. and navigation will be given based on the rules adopted. To fulfill this purpose, the agent should consist of the following four main modules.

1. Definition and Auto-Driven Module

It is used to wrap various drivers of heterogeneous SOs to form a driver library which enables the newly plugged SO to be "Plug and Play" in a Smart Gateway with only simple definition of some basic parameters. Two driven modes, standard interface driven and the third-part driven, are designed in this module.

2. Reasoning Model

It is designed to enhance the intelligence of the agent. Rule-based methods are adopted to accelerate agent to make decision based on real-time manufacturing environment and production logics. The fundamental element of a rule is function. A function has a name, a set of arguments, and a return value. Function itself can be an argument of another function.

3. Services Module

It is responsible for wrapping agents into standard web services so that they can be easily invoked through internet. Three types of services, namely "Reading/Writing service", "data processing service" and "input/output service", are involved in this module.

4. Communication Module

It is used to implement information exchanging between SO, agent and Smart Gateway. The communication between SO and agent can be achieved by auto-driven strategy, while the communication between "agent to agent" and "agent to Smart Gateway" both adopt SOA.

9.4.3 soUDDI

As discussed above, agents are exposed as web services from Smart Gateway. A soUDDI platform is developed to manage these services so that they can be easily found and invoked for implementing real-time manufacturing.

Figure 9.3 shows the architecture of soUDDI, which is a platform-independent, XML-based registry for the agents' services. As seen in the middle of Fig. 9.3, the services of agents are published to soUDDI and thereafter invoked by the service requestors to conduct real-time manufacturing activities. A complete process of using soUDDI involves three main phases. In the first phase, the distributed services of agents are registered and published at soUDDI, as indicated by "(1) Publish". During the publishing process, detailed information of each service of an agent, such as its location, capability as well as the interfacial description will be provided. Then, the published services of agents can be searched according to the real-time

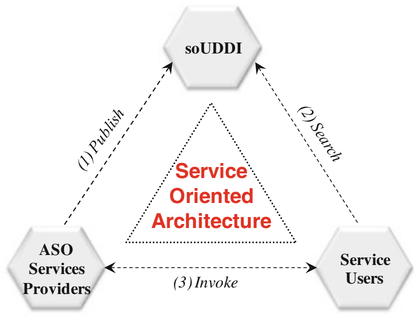

Fig. 9.3 The architecture of soUDDI

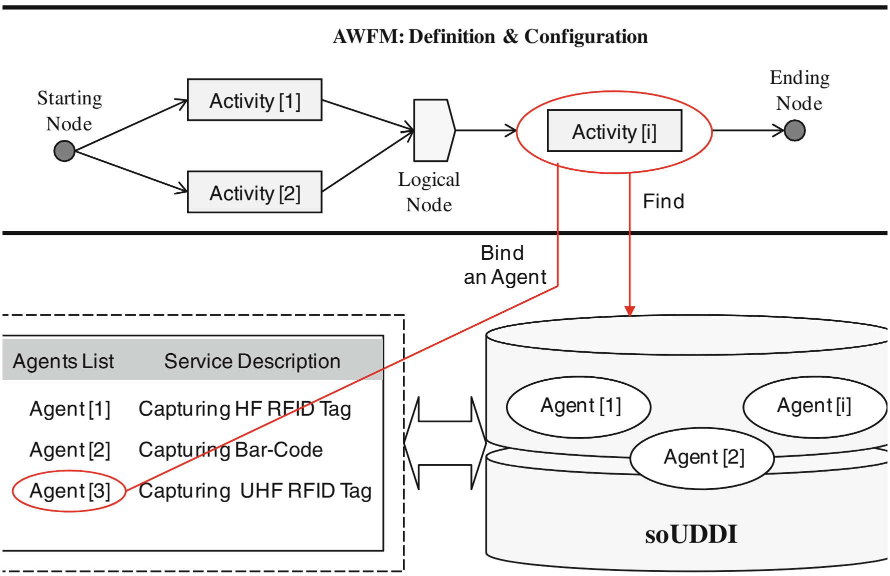

Fig. 9.4 Agent-based workflow management model

requirements from soUDDI, as indicated by "(2) Search". The third systems can bind the selected services and invoke them, as indicated by "(3) Invoke". During the execution phase, the users or other systems could invoke the corresponding services of agents to capture the real-time manufacturing information.

9.4.4 Agent-Based Workflow Management

Figure 9.4 shows the AWFM framework. Specifically, the topology of activities involved in the manufacturing process and its corresponding data capturing workflows will be defined in this AWFM model first. Then, specific agents (smart objects) will be chosen for the execution of each activity from soUDDI based on their published capabilities. In the actual execution stage, AWFM will coordinate the data collection and transformation activities based on a defined set of rules and knowledge.

There are three basic elements in AWFM: activities, business logic, and agents (participants). Activities are specific tasks in a process while business logic indicates how activities are performed and under what trigger conditions. Agents (Participants) represent the operators who will fulfil the tasks of activities.

Referring to Workflow Management Coalition (WfMC), an industry-wide consortium of workflow system venders, the implementation of AWFM consists of two core components, namely designer and executor. A workflow designer is a graphical interface application enabling shop-floor managers to configure or reconfigure the flow of data collection without using any programming languages. A workflow executor is responsible for instantiating workflows and the associated agents to perform the defined activities.

9.5 Real-Time WIP Management System

9.5.1 Overall Architecture

It is well-known that work-in-progress management system plays a critical role in manufacturing system. It controls the material and information flows, monitors the WIP level for each workstation/stock, tracks the statuses of each manufacturing object and the progress of each production order, and also responds to requests from the shop floor [34, 35]. In a UM framework, WIPMS facilities of shop floor are required to implement real-time traceability, visibility and interoperability in improving the performance of shop-floor planning, execution and control [8].

Figure 9.5 shows the overall information architecture of WIPMS. It acts as a sandwich and plays an important role to manage and control the material and information flows in the entire shop floor. Following this architecture, the users or other systems can get or update the real-time WIP information by easily sending a request to WIPA. Four main components are involved in the designed WIPMS, namely (1) Data Source Service, (2) WIPA: Work-in-progress Agent, (3) Gateway Data Service, and (4) Registry and Repository.

Data source service provides data acquisition, processing and updating services for sharing and integrating information between WIPA and EISs. WIPA is responsible for dynamically forming the WIP information instance in terms of the specific production process, as well as establishing the binding relationship between WIPA and relevant Gateways. Gateway data service provides standard methods for WIPA to get or update real-time manufacturing information from or to corresponding gateways. Registry stores all the offline data for definition and configuration stages, e.g. definition of gateway, wipML schema, instances and configuration

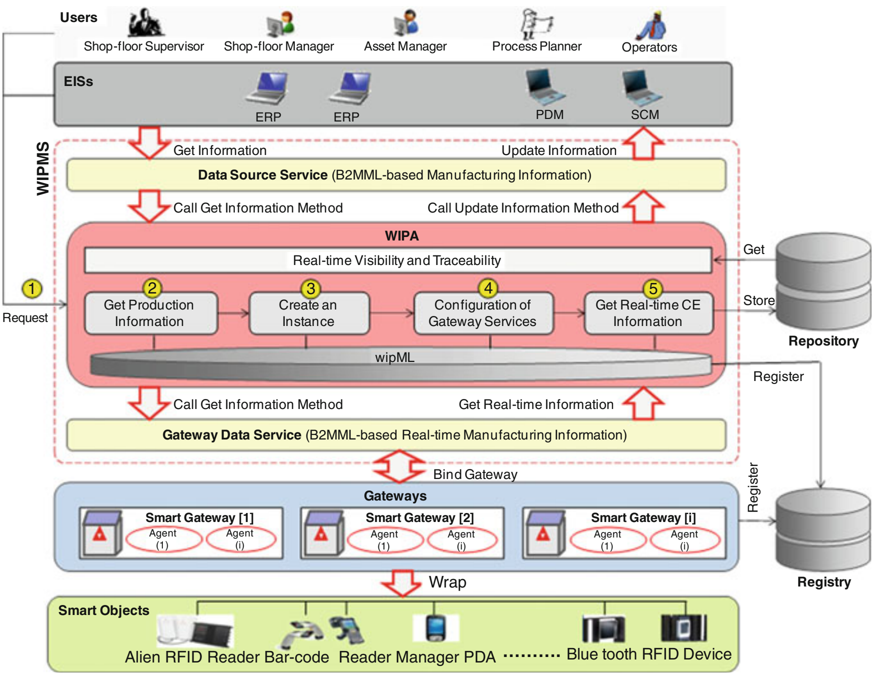

Fig. 9.5 Overall architecture of real-time WIP management system [8]

information between WIPA and gateways. Repository stores the extracted information from EISs schemas and the online data captured by distributed gateways during manufacturing execution.

9.5.2 Working Logic of WIPMS

A procedure of using the WIPM for different users or systems can be also seen in the middle of Fig. 9.5.

At the beginning, the users or systems submit their request to WIPA. For example, the request can be a real-time progress of a production order. Then, the WIPA will invoke the data source service to get the necessary information relevant to the production order such as the product BOM, schedule information etc. from the up-level EISs. Based on the gotten manufacturing information and the information schema (wipML) of WIPA, a new WIPA instance is created, which includes the manufacturing BOM information. For each node of the manufacturing BOM, its dynamic information nodes can be captured by the gateway data service. And the binding model is used to build up the bind relationship between the dynamic information nodes and the corresponding gateways. During execution, the huge manufacturing information captured by each gateway will be processed by critical event model according to the user's request. Finally, the result of the request will be either returned to users by visible explorers or updated to the corresponding EISs by data source service. Here, the visible explorers provide graphic user interfaces for effectively managing and controlling the material and information flows in the entire shop floor.

9.5.3 Core Technologies of WIPMS

9.5.3.1 Data Source Service

The objective of data source service is to build up a bridge for information communication between WIPA and heterogeneous EISs. Due to the difficulties of information sharing and integration among heterogeneous EISs, B2MML standards are adopted in this component to provide standard schemas for manufacturing elements. The inputs of this component are the parameters of the data source of the EISs which users want to acquire or update information from or to, while the outputs are the standard information based on B2MML schemas.

Three main modules are involved in this component. The first is definition of data source module. It is responsible for defining and creating configuration file for describing the information of various data source of different EISs. The result of this module is an XML-based definition file which consists of multiple data source nodes, which records the main parameters, attributes (e.g., data source, data connection driven, data structure etc.) and Standard Query Language (SQL) statements for the corresponding database. The second is data transmitting service module. It provides standard methods such as Get_Data_Method() and Update_Data_Method() for users or systems to attain or update information they needed from or to various EISs. It adopts web service architecture and the input parameters of each method are defined as standard XML segment. The third is data processing module. It is used to process the isolated and inconsistent manufacturing data in shop floor as standard information schema. Ten types of B2MML schemas such as personnel, material, equipment, maintenance, production capability, process segment etc. are adopted in this module for describe the information of man, machine, material and production process etc.

9.5.3.2 Gateway Data Service

The objective of gateway data service is to establish an information exchange channel between WIPA and various Smart Gateways. Following service oriented architecture, the reading and writing functions of Smart Gateway can be encapsulated as web services that can be easily published, searched and invoked through internet. WIPA can easily call them through gateway data service to get or update the real-time information without considering which types of smart objects are installed at the gateways.

The outputs of this component include (1) the real-time manufacturing information at gateways that exposes as standard B2MML schemas; (2) the updated manufacturing information at gateways. Similar to data source service, this component also has three main modules. Definition module is responsible for defining and creating configuration file for describing the information of various gateways. For example, gatewayID is a unique ID to each physically deployed gateway. Manufacturing resource ID indicates that the gateway is used to capture the real-time information occurred at the corresponding manufacturing resource. Data transmitting service module provides standard methods such as Write_Data_Method() and Read_Data_Method() for WIPA to get or update real-time manufacturing information they needed from or to distributed gateways. Data processing module is used to process the real-time manufacturing data captured by gateways as standard information schema. To make the manufacturing data more meaningful and be easy to understand by other systems, B2MML schemas are also adopted to convert the real-time data to uniform manufacturing information.

9.5.4 WIPA: Work-in-progress Agent

WIPA acts as a core component in WIPM framework. On the one hand, it is also responsible for establishing WIP instance by extracting the necessary information or updating changed information from or to heterogeneous EISs through data source service. On the other hand, it is also responsible for configuring the distributed Gateways according to specific logical relationship to get real-time information of WIP in the entire shop floor.

The structure of WIPA is described in Fig. 9.6. Its inputs are the information of BOM, scheduler, CAPP and real-time information captured by relevant Smart Gateways. Its outputs are the real-time information related to products produced, materials consumed, exceptions etc. of individual manufacturing resource and the overall real-time production progress, materials flow and production disturbances etc. of the entire shop floor. Three models are included in WIPA. They are information model, binding model and critical event model.

1. Information Model (wipML)

It is used to build up an information structure of WIPA, which consists of seven basic B2MML schemas such as production, person, equipment, material, process segment, product etc. as seen in Fig. 9.7. This information model is consistent with the manufacturing shop-floor hierarchy that is a manufacturing shop floor hosts one or more production lines/work-cells. Each production line or workstation is involved of a variety of manufacturing objects such as persons, equipments; materials etc. and different production lines are often designed to enable different production processes.

To describe the information model of WIPA, a wipML schema is developed which contains and extends the set of B2MML standards in a pragmatic and innovative manner for the definition and operation (e.g. messages) relevant to

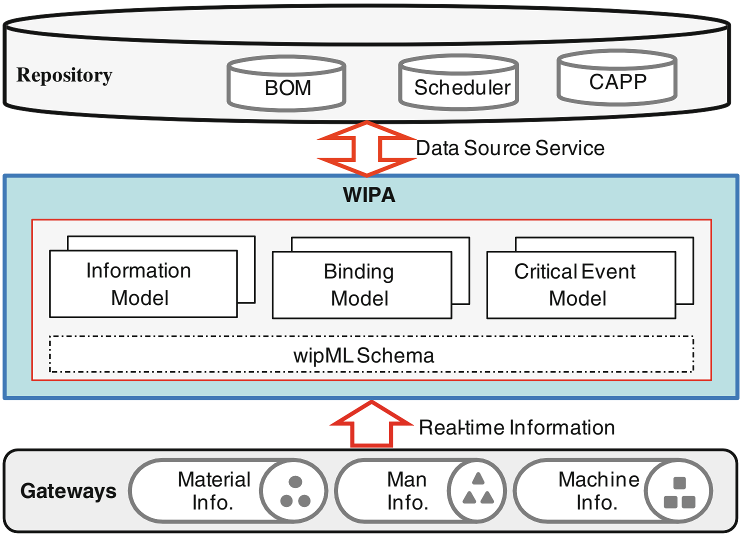

Fig. 9.6 Structure of WIPA [8]

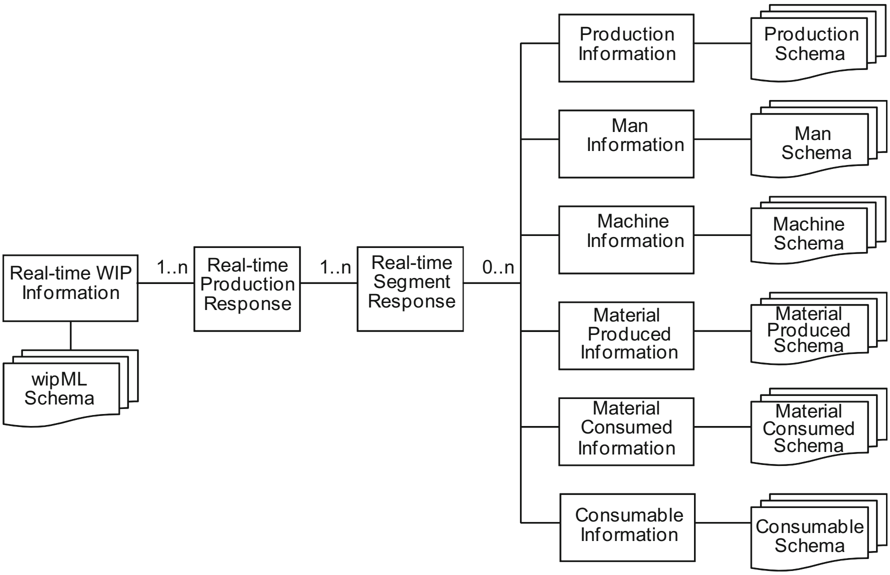

Fig. 9.7 Information model of WIPA

WIP. For each wipML instance, it stores the information such as product BOM, production order, production scheduler, production process etc., as well as the input/output relationships between WIPA and gateways. Following wipML schema and gateway data service, the Smart Gateways know where the captured real-time manufacturing information should be sent to.

2. Binding Model

Generally, different manufacturing shop floors may probably have different production processes. Even if in the same shop floor, different products also have different production process.

To effectively address these problems faced in real-life manufacturing environment, a flexible and configurable binding model between WIPA and Smart Gateways is proposed. Two modules are involved in this binding model, namely search engine and configuration. Search engine aims to find the suitable gateways from registry where is used to register and publish all the gateways installed in a manufacturing shop floor, plant or enterprise. Configuration is responsible for binding the information relationship between WIPA and the selected suitable gateways. After configuration, the WIPA and selected gateways could know where inputs are obtained from and the captured real-time information is sent to respectively.

3. Critical Event Model

It is used to help users to obtain more meaningful and actionable information from large amount of low level events and to control the event-driven information systems. It establishes an aggregation of series of the events from agent-based smart object to form high level events. Critical event is composed by two main parts: definition and executer. Definition is used to create new composite event types by establishing the relationship among the events of agents. The relationship includes information, logic and sequences flows and is also described in a unified model called ceXML schema. Executer acts as an event engine and is used to execute critical event according to the pre-defined ceXML.

According to the requirements of WIPMS, four types of critical events are defined. The first is manpower regulation, which is responsible for establishing the events of gateways relevant to employees. The useful information such as productivity of each operator can thus be tracked and traced. The second is equipments regulation. It reflects the information of all the equipments by compositing the events of gateways related to equipments. Through this critical event, the information of corresponding equipment such as dynamical capacity and produced WIP items can be tracked and traced. The third is materials regulation. It is used to track and trace the status and history of each material. The fourth is production regulation. It can be used to track and trace the WIP inventories and product progress of the shop floor on the one hand, and monitor the production disturbance on the other hand.

9.6 Case Study

This section builds a proof-of-concept demonstration to describe how the presented Smart Gateway works and how to implement real-time visibility and traceability of WIP. The motivating scenario uses our previous research work reported in the international journal of computer integrated manufacturing [8].

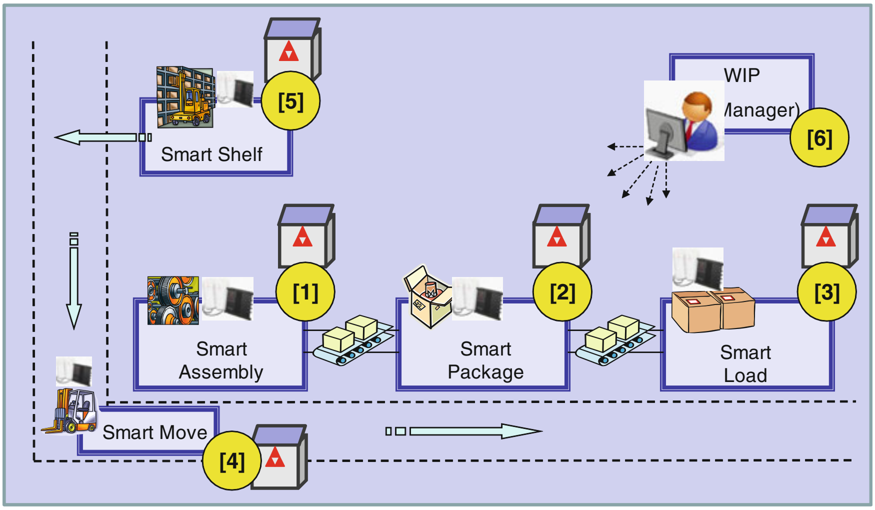

Fig. 9.8 Overview of the motivating manufacturing shop floor [8]

9.6.1 Description of Motivating Scenario

The motivating scenario is about a flexible manufacturing system (FMS). For simplicity of understanding but without loosing generality of principle, some basic manufacturing resources are selected for configuring a practical proof-of-concept demonstration. The configuration of the FMS depends upon the structure of the product (variant) to be assembled. As shown in Fig. 9.8, this demo FMS consists of the following main components, namely,

- Three main workstations (for assembling, packaging and loading van toys, respectively), denoted as (1), (2) and (3) in Fig. 9.8;
- One trolley for shop-floor logistics, denoted as (4) in Fig. 9.8;
- One shelf for storing raw materials and WIP items, denoted as (5) in Fig. 9.8.

9.6.2 Configuration of RFID-Enabled Ubiquitous Manufacturing Shop Floor

In order to create a RFID-enabled smart ubiquitous manufacturing shop floor, it is first necessary to identify shop-floor objects to which RFID tags and/or readers and/or other types of wireless devices are attached. RFID tags are deployed in several ways.

For RFID tags, firstly, staff members have their staff cards which can be read and written by the RFID readers. Secondly, one of the components in the product assembly is considered critical and each critical component is attached with a RFID tag. This tag, as a mobile memory of the "smart" WIP products, plays important roles throughout the assembly process and even retained for subsequent supply chain applications. Thirdly, RFID tags are attached to all the pallets for holding WIP materials, including components/parts, scraped materials, and semi-finished subassemblies and finished product assemblies. These tags are not only used for tracking the flow of materials but also for controlling the WIP inventories. Such field information will in turn be fed back and used for production planning and scheduling. Finally, each location of shelf is attached with RFID tags. These tags are used to bind the information between the location and the materials at this location.

For RFID readers, as described previously, they should be integrated to a gateway and wrapped as corresponding web services so that they can be easily invoked for capturing real-time manufacturing information. The detailed procedure of how to wrap smart objects integrated into Smart Gateway and publish them to registry can be seen in our relevant paper [2]. In this case, it is assumed that each workstation is equipped with a Smart Gateway that hosts one RFID reader. This gateway is multi-functional and is able to read tags attached to different objects. Smart Gateways are also available at the shelf for capturing the real-time information of the tags attached to different objects. Finally, trolley with which pallets are moved across the shop floor is equipped with a gateway.

After the configuration of SOs and the five gateways, it is ready for creation of WIPA and establishing the binding relationship between WIPA and Smart Gateways. As seen in Fig. 9.8, there are five gateways placed at the different manufacturing resources for capturing real-time manufacturing information in the scenario shop floor, denoted as Smart Gateway (1) to Smart Gateway (5).

9.6.3 Creation and Configuration of WIPA

Three main steps are needed for creating an instance of WIPA as seen in Fig. 9.9. Firstly, a WIPA instance should be created according to its information model. In this stage, data source service plays a very important role because the required manufacturing information is stored in various EISs with different database. For example, the production plan is stored in ERP whose database is Oracle, CAPP information is stored in PDM that uses SQL Server as its database, and advanced planning scheduler is stored in MES that uses My SQL database. The created WIPA instance establishes the information relationship between WIPA and corresponding manufacturing objects based on the hierarchy and data structure designed before. Two types of information, namely static and dynamic information, are involved in the formed instance of WIPA. Static information refers to the information that seldom changes during execution unless the exception occurs, for example, CAPP, production plan. The dynamic information refers to the information that timely changes, for example, consumed materials, produced products/semi-products, etc.

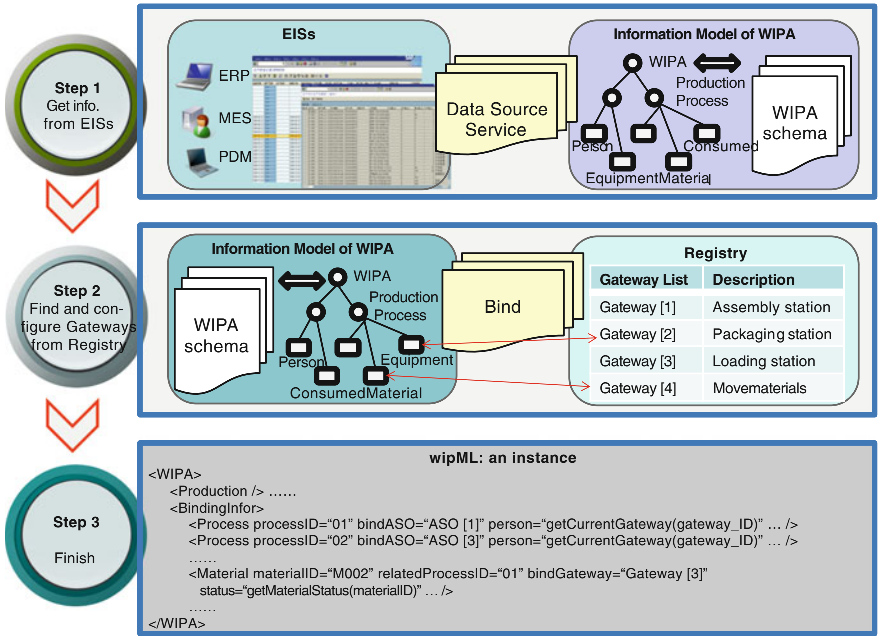

Fig. 9.9 Procedure of creating a WIPA instance [8]

Then, for each dynamic information node of the WIPA instance, the gateway data service component is used to find and bind the suitable Smart Gateways for providing the real-time manufacturing information to this node. During the execution, the real-time data capturing or updating operations can be conducted by invoking the methods of the gateway data service. And this node can thus be timely updated as well as the binding gateway can timely receive the information from WIPA.

After all the involved dynamic information nodes of the WIPA are configured by this way, an XML-based definition file is created which records the bind relationship between the nodes and gateways.

9.6.4 Real-Time WIP Management

For better understanding, let us describe a scenario to demonstrate how the presented Smart Gateway and WIPMS facilitate the real-time WIP management in this demo.

Supposing the RFID-enabled ubiquitous manufacturing shop floor will produce some van toys and packaged them to container for transporting to customs, the corresponding workflow could be described as following:

1. Production material supply

This process is executed by internal logistic operators who are primarily responsible for choosing and executing the internal logistics orders to move WIP items between shop floor inventories and buffers of production workstations. During the moving execution, each activity such as picking up materials, current location and unloading materials are tracked and traced. In addition, the relevant information of the accurate number and type of materials picked up from which location of the warehouse and unload them to which location of the shop floor at which time by which operator etc. is also tracked and traced for WIP management.

2. Production-van assembly

Because the Smart Gateways installed at the different stations in the assembly line work in more or less similar way, let us study on the Smart Gateway [1] of the assembly station for assembling van. The real-time visibility explorer will provide intelligent navigation for assembly operator, and the relevant process could be described as following.

At the beginning, the assembly operator comes to this station and uses his staff card for login. Workstation Explorer will prompt the operator to check his assembly tasks when he accesses, as seen in Fig. 9.10a.

Before assembly, the operator needs to check all the required items needed by the facilities provided by workstation explorer seen in Fig. 9.10b.

If all the required items are checked successfully, a detailed assembly process prompts to illustrate how to assembly a van as shown in Fig. 9.10c. For example, this assembly process includes the following steps:

Step 1: Get a van body from the in-buffer of this workstation;

Step 2: Get a wind shield from the in-buffer of this workstation and put together with the van body to form a new WIP item;

Step 3: Get a roof from the in-buffer of this workstation and be added to the new WIP item formed in Step 2 to produce the finished product "van".

After each finished product is produced, the real-time visibility explorer will prompt the operator to put it into the out-buffer of this station, as seen in Fig. 9.10d. These processes are repeated until all the assembly tasks of the operator are finished.

3. Real-time WIP monitoring and control (WIPMS explorer)

During manufacturing execution stage, the WIPMS Explorer is responsible for monitoring and controlling the entire shop floor according to the critical events. Its main users are shop-floor managers and/or assembly line supervisors. The WIPMS Explorer provides facilities mainly for information display and also acts as interface with corresponding ERP decision support modules. Therefore, its main function is to organize the real-time information captured from gateways installed at the corresponding manufacturing resources. The mechanism of organizing the real-time information in different ways to serve different purposes is based on the critical event model. As the user interface, the WIPMS Explorer is where the supervisors can sense the shop floor changes and disturbances. The supervisors can then take corrective actions by manually using corresponding APS explorers. As shown in Fig. 9.11, the WIPMS Explorer provides facilities for the manager/ supervisor to monitor the following aspects of the assembly line:

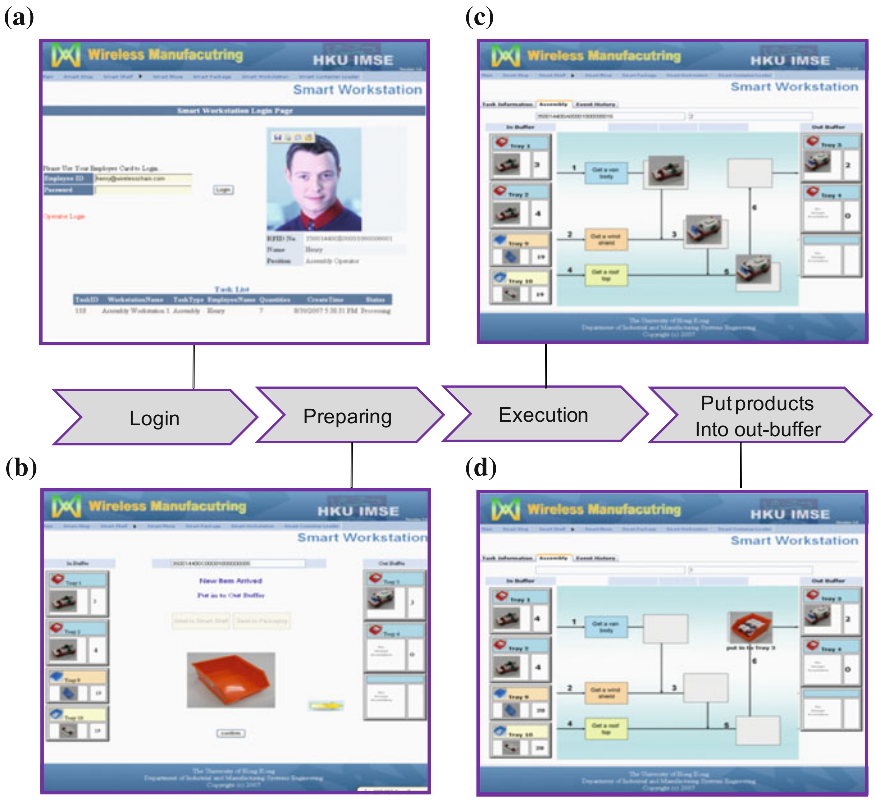

Fig. 9.10 Real-time visibility for van assembly at smart gateway (*1*) [8]

1. Real-time status of each smart workstation including total production demand and finished, current task in process, number of Scraps, wellness of each workstation, and current location of Smart Move, seen in Fig. 9.11a;

2. Real-time production process of each smart workstation including total demand and current output, number of scraps, net completed and percentage, and status of buffer, seen in Fig. 9.11b;

3. Real-time progress of production order including total demand of each component, total completed of each component and percentage of completion, seen in Fig. 9.11c;

4. Manufacturing event tracing including operational events of each individual Smart Workstation, i.e. event history record, and logistics between each two Smart Workstation, i.e. incoming material of each station and outgoing material of each station, seen in Fig. 9.11d.

The above functions allow managers and supervisors to monitor and control the production remotely if they are not at the shop floor as long as they have the access to the Internet.

Fig. 9.11 Real-time visibility and traceability of WIP [8]. **a** Real-time visibility of workstations **b** real-time visibility of product BCM **c** tracing information of materials **d** tracing information of product

9.7 Concluding Discussion

UM is emerging as an advanced manufacturing technology (AMT). It relies substantially on wireless smart objects such as Auto ID sensors/RFID and wireless information networks for the collection and synchronization of real-time field data from manufacturing shop floors. UM enables the shop-floor management to realize paperless working environment, real-time WIP tracing and tracking, and ultimately improve the efficiency and effectiveness of production supervision and decision and largely reduce the production disturbances.

This chapter has proposed a referenced UM infrastructure. Under this infrastructure, the overall architecture of Smart Gateway and WIPMS is presented for capturing the real-time manufacturing data and implementing dynamic WIP management. Following the service-oriented architecture, smart objects enabled ubiquitous manufacturing information infrastructure has been established. Through this infrastructure, both the upstream manufacturing information and the real-time manufacturing data of individual manufacturing resource could be obtained and captured by data source service and gateway data service respectively. Then, WIPMS can be used to implement real-time WIP tracing and tracking throughout the shop floor according to the specific production process. The successful proof-of-concept demonstration has allowed us to gain useful insights and experience. The prototype provides a foundation to migrate to a successful real-life industrial environment as an actual application.

The current work will be further extended in our future research from the following aspects. Firstly, the proposed data source service has only revealed a concept and applied to some open source EISs, and a great effort should be needed to support more various EISs of different companies. In addition, up-level decision based on timely shop-floor WIP information should be investigated for optimal production control. For example, real-time production scheduling/re-scheduling, real-time internal logistics planning and scheduling etc. Finally, data mining for production prediction based on real-time execution information monitored by critical event should be taken into account for reducing shop floor disturbance, e.g., how to implement production exceptions alerts and quality control in a real-time manufacturing environment.

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