RFID-ENABLED JUST-IN-TIME LOGISTICS MANAGEMENT SYSTEM FOR “SHIP” − SUPPLY HUB IN INDUSTRIAL PARK

T. Qu1,2*, H. Luo1, N. Cao1, J. Fang1, R.Y. Zhong1, A.L.Y. Pang1, X. Qiu1 and G.Q. Huang2

1Department of Industrial and Manufacturing Systems Engineering
The University of Hong Kong, Hong Kong, P.R. China
quting@hku.hk

2School of Electromechanical Engineering
Guangdong University of Technology, Guangzhou, China

ABSTRACT

Supply Hub in Industrial Park (SHIP) is a public depot which provides shared warehouses and fleets for enterprises to reduce their logistics costs through economy of scale. SHIP normally adopts milk-run logistics for material collection and distribution, in order to achieve Just-in-Time (JIT) operations to reduce the suppliers’ and manufacturers’ shop-floor inventories. Instead of once processing a full order, smaller-lot orders from multiple suppliers/manufacturers are mixed and fulfilled in a milk-run round. Milk runs go in parallel with the production processes of all manufacturers, cutting down the shop-floor stocks. However, such lean logistics is subject to failure if production dynamics cannot be timely and accurately captured and handled by the logistics operations. This paper introduces a RFID-based small-lot and high-frequency JIT production logistics management system. Real-time materials outputs and consumptions are captured by RFID-enabled manufacturing execution systems deployed at both suppliers and manufacturers, generating adaptive materials collection and distribution orders respectively at the two sides. Orders are dynamically split into pieces and consolidated into a sequence of shared logistics tasks which are then scheduled based on the real-time status of logistics resources and progresses. Through the developed RFID-enabled operation facilities, the materials collection and distribution around SHIP are collaboratively and accurately executed in a small-lot and high-frequency milk-run mode logistics.

* Corresponding Author
INTRODUCTION

Industrial parks have been playing more and more important role in stimulating the economic and industrial development. An industrial park has been defined as a tract of land developed and subdivided into plots according to a comprehensive plan with provision for roads, transport and public utilities with or without build-up factories, for the use of a group of manufacturing enterprises [1]. It was estimated by UNEP (United Nations Environmental Management) that there are approximately 20,000 industrial parks all over the world by 2001 [2]. Enterprises in an industrial park share cost-effective infrastructure and communal services, and have more opportunities to cooperate with each other. During the enterprises’ continuous expansion of production scales, difficulties of obtaining land have become the greatest barrier and therefore the most valuable resources in the development of industrial parks. A special 3PL form advocating the sharing of logistic site as well as the related facilities and services among multiple enterprises named supply hub in industrial park (SHIP) has gradually emerged.

The concept of SHIP is derived from supply hub, which is a depot geographically approximate to a specific manufacturer, used to store and distribute their raw materials. A SHIP is normally located in an industrial park, composed of a public warehouse and a transportation fleet both managed by a 3PL operator. The operation of SHIP differs from that of supply hub in two aspects: (1) supply hub offers logistics services to one specific manufacturer, while SHIP serves for multiple manufacturers in the industrial park; (2) supply hub is defined an intermediate point between suppliers and manufacturers, mainly warehousing raw materials, while the service scope of SHIP also include final products [3]. Through sharing SHIP, both individual enterprises and industrial park have been relieved of the land acquiring pressure on the one hand, and been enabled to obtain professional logistics services on the other.

The maturation of manufacturing technologies has forced manufacturers to resort to 3PL for cutting their non-value-adding production logistics costs. Apart from the economy-of-scale logistics acquiring (e.g. shared public warehouse), the other recently advocated service of 3PL is to provide frequent punctual production logistics, including material collection (from suppliers) and distribution (to factories). The 3PL splits the daily material orders of a customer (either supplier or manufacturer) into several pieces, and attune each piece of logistics operation with the customer’s production process [4]. This mode not only enables the customer-side WIP inventory to be largely reduced, but allows dynamics occurring in the production process to be timely responded by 3PL.

In the past decade, the system of punctual and frequent delivery has already been widely adopted by many largely manufacturers, especially by those leading automotive makers [5]. They normally establish a distribution depot or 3PL cross-dock of appointed suppliers set up in the vicinity of their plants. Materials/parts from suppliers are collected, sorted and consolidated in the depot, and then delivered at the time specified by the manufacturer, in the specified quantity, to the work area for the specified process [5]. At the distribution depot, based on information from car assemblers, the required parts are sorted according to each specified time, delivery point, and quantity, and are transferred onto the delivery trucks. Before deliveries can be made in this way, parts brought in by a large truck need to be divided up into small lots at the cross-dock. This 3PL cross-dock is engaged in punctual and frequent delivery, daily sorting approximately 20,000 different parts delivered from about 250 parts suppliers.

Such mode of small-lot and high-frequency JIT (Just-in-Time) logistics is most suitable to be implemented in industrial park through the operation of SHIP (refer to as “SHIP JIT logistics” in this paper). Such logistics mode could not only enhance the supplier-side load efficiency, but also lower customer-side inventory. However, SHIP JIT logistics is currently suffering from various challenges when putting into practical use in both manufacturing and industrial
parks. The problems mainly result from the inefficient information collection, process and utilization, spreading in two levels. First, current logistics plans are made based on the theoretical status of logistics resources. When they are release for execution, various practical dynamics will make the resources unavailable and thus plan infeasible. Second, logistics operators may not strictly follow the plan to execute the logistics operations due to their carelessness or laziness, especially when dealing with complicated combinations of materials. For JIT logistics which emphasize on the coordination of adjacent stages, a delay in one stage may cause the whole process lose JIT due to domino effect.

RFID (Radio Frequency Identification) has been emerging as an important tool which facilitates the automatic data collection from manufacturing and logistics sites [6-8]. This paper aims to introduce a RFID-enabled JIT logistics management system for SHIP to realize the small-lot and high-frequency material collection and distribution between suppliers and manufacturers in an industrial park. Several specific objectives are to be achieved. First, Auto-ID/RFID enabled smart objects and gateways previously developed for realizing shop-floor RFID solutions will be adapted and extended to create smart SHIP logistics environment. Second, adaptive decision models and methods will be developed to enable SHIP managers to make real-time online plan and schedules for the JIT logistics process. Third, real-time execution facilities (explorers) are to be developed for the key logistics stages of a SHIP-based logistics process to facilitate the corresponding operators to execute the logistics plan/schedule in a traceable way. Last but not least, the cutting-edge technologies for industrial informatics will be adopted for system development to allow maximum system integrity and scalability, and third-party customizability and usability.

The remainder of this paper is organized as follows. Section 1 will analyze the current challenges of the whole logistics operations collaborated among three SHIP stakeholders. A RFID-enabled JIT logistics system is then designed in section 2 in terms of its information infrastructure and operational logics. The development details of the system modules are introduced in section 3. Section 4 will give a case study to illustrate the usage of the system. Conclusions are drawn in section 5.

1 OPERATIONAL CHALLENGES OF SHIP PRODUCTION LOGISTICS

1.1 SHIP Stakeholders

From the supply chain perspective, there are mainly three kinds of stakeholders of an industrial park, namely manufacturer, supplier and SHIP. In this project, manufacturers refer to the firms whose products will be shipped outside the industrial park, while suppliers are firms whose products of a portion of products are the production materials of an industrial park manufacturer.
Manufacturers are the main stakeholders of an industrial park. They locate their factories in industrial park due to not only the cost-effective infrastructure and communal services, but also the opportunities to cooperate with other peer companies. As previously mentioned, manufacturers tend to rely on SHIP’s public warehouse to reduce their warehousing cost and seek small-lot and high-frequency material distribution service from SHIP’s fleet to reduce WIP inventories.

Suppliers are the second kind of stakeholders. Although suppliers may locate outside the industrial park, manufacturers are tending to gather more and more their key material supplier in the vicinity (within the same industrial park) in order to enhance the overall supply chain response for market changes.

SHIP operator is normally a 3PL provider, providing both public warehousing services and transportation services. Both manufacturers and suppliers are the customers of SHIP. In this project concerning with JIT logistics, SHIP mainly performs material order consolidation function. Material Collection Orders (MCO) from multiple suppliers are consolidated and transport to SHIP through small-lot and high-frequency in-bound milk-run logistics. After a cross-docking process where materials are sorted to the real-time Materials Distribution Orders (MDO) from manufacturers, a small-lot and high-frequency out-bound milk-run logistics will also be performed to distribute materials to multiple manufacturers.

1.2 Problem Analysis of Traditional Production Logistics in SHIP

2.2.1 Milk-Run Material Collection between SHIP and Suppliers

A supplier makes and executes its production schedule following certain production coordination scheme with a manufacturer, e.g. production Kanban system. In order to reduce the suppliers’ product (material for manufacturer) inventory, SHIP is requested to periodically collect the finished products from their factories. For each collection period, orders from suppliers are reviewed and the most urgent orders are picked up and consolidated. A “milk-run” material collection process will then be conducted, where a truck from SHIP makes a circuit to visit the related suppliers for material collection and transports the materials back to SHIP simultaneously, as the left part of Figure 1 shows.

There are three problems existing in the material collection process. First, an operator may not strictly follow the decided plan to finish the material collection process. A truck driver
often picks up materials from a supplier at his convenience (both route and quantity). As a result, the collection plan made toward optimum cannot be executed in the planned way. Second, as the milk-run process involves multiple varied suppliers which have daily changed production schedules and thus highly dynamic material collection requirements, the operators may easily confuse the collected materials/pallets when loading from suppliers’ shipping docks and unloading to the SHIP’s receiving docks especially they use the same pallets. Third, disturbances in the collection process can be reported to SHIP only after the truck completes the milk run. With such a sequential information transfer, both SHIP and manufacturers cannot deal with the disturbances in the earliest time, such as arranging concurrent order picking from SHIP inventory during the cross docking, and therefore affect the efficient execution of the JIT process.

The CAUSES of the above problems are: Lacking of (a) Auto-ID tags deployed at suppliers’ collection point (see Figure 1), and materials pallets, as well as Auto-ID readers attached with truck drivers to record the visited suppliers; (b) lack of real-time data synchronization between the collection process (truck drivers) and SHIP management.

2.2.2 Cross-Dock In SHIP

Material collected from suppliers need to be cross-docked before they are distributed to the manufacturers, as shown in middle of SHIP in Figure 1. This is normally due to two reasons. First, a supplier may serve for multiple manufacturers, but materials collected from this supplier in a milk run may need to be distributed to manufacturers in different batches. Second, materials are normally collected from suppliers in bigger lots (i.e. more pallets) than distribution to manufacturers. This is relevant to the first reason that materials are served for multiple manufacturers, and also because the average distance between supplier and SHIP is normally longer (may be outside industrial park) and thus bigger lots and heavier trucks are used for longer distance transportation.

Therefore, after materials are collected from suppliers, they will be sorted to suitable lots through cross-docking process to enable small-lot and high-frequency material distribution for manufacturers. In order to maintain an efficient JIT process, suppliers and manufacturers share the same pallets for loading and transporting materials. Therefore, complicated pallet sorting operations are avoided, while the cross-docking process simply includes the pick-up of those collected pallets which are needed in next milk-run distribution tasks.

There are three problems existing in the cross-docking process. Cross-docking operator may not strictly follow the plan for material picking and putting. However, the materials/pallets stored in different receiving docks may have been designated to a specific manufacturer. Any illegal operation will cause a series of cross-dock and distribution plan infeasible. Similarly, putting materials in a wrong shipping dock will also confuse the distribution operators when they start loading materials there.

The CAUSES of the above problems are: Lacking of Auto-ID tags deployed to receiving docks and shipping docks, as well as Auto-ID readers attached with cross-docking operators to record the picking and putting location are the main cause of this problem.

2.2.3 JIT Milk-Run Material Distribution Between SHIP And Manufacturers

Similar as in the material collection process, cross-docked materials will be distributed to multiple manufacturers based on the consolidated material distribution orders and also through a milk-run material distribution process. As compared to the material collection, this distribution milk-run process is a smaller-lot and higher-frequency one, and is normally performed by lighter trucks. It should be mentioned that, due to the production dynamics of manufacturers, e.g. customer order changes, collected materials in SHIP may not be used as planned, resulting in inventory in SHIP. Therefore, a new distribution order will be fulfilled from the SHIP inventory in first priority, instead of from cross-docking process.
The three problems discussed in the material collection process, i.e. not following distribution plans, materials confusion, and inefficient information transfer are exactly the problems in this process. Due to the higher frequency of milk runs as well as the abovementioned worsen consequence, these operational problems will also cause larger impacts.

The CAUSES of the above problems are: Lacking of (a) Auto-ID tags deployed at manufacturers' distribution points (see Figure 1), as well as Auto-ID readers attached with truck drivers to record the visited manufacturers; (b) lack of real-time data synchronization between the distribution process and SHIP management.

2 OVERALL DESIGN OF JUST-IN-TIME LOGISTICS OPERATION FOR SHIP

From the above analysis, the small-lot and high-frequency JIT logistics conducted by SHIP is a high-speed coupling system which emphasizes on the efficient coordination and accurate cooperation among different logistics/production partners. It emphasizes on the decision adaptivity and execution accuracy. At current stage, its effective operation is mainly constrained by the lack of an efficient real-time information infrastructure to perform information collection, process, application, as well as the associated decision support mechanisms which will not be covered in this paper.

Information value-adding points which simplify data collection, monitor data authenticity and

2.1 Real-Time Production Logistics Information Infrastructure

A real-time manufacturing information infrastructure called AUTOM has been developed by [7] and [9], which has been successfully used for RFID system implementation in several real-life manufacturing companies. AUTOM defines an easy-to-deploy and simple-to-use information infrastructure for manufacturers to achieve real-time and seamless dual-way connectivity and interoperability between application systems at enterprise, shop floor, work cells and RFID devices [10]. A reference structure of AUTOM is given in Figure 2. It is consistent with the standard enterprise hierarchy defined by ISA-95 enterprise-control system integration standard (http://www.isa.org), as shown in the left part of the figure. An enterprise hosts one or more manufacturing sites or areas (e.g. factories or warehouses), each of which consists of several production lines/cells or logistics groups (e.g. assembly line, storage area, fleet). Each line/cell/group involves a variety of operations which are concerning with both manufacturing resources (e.g. materials, equipments and operators) and their logical combinations (e.g. product assembling). Implementing enterprise information systems to be consistent with this standard hierarchy will ensure the system applicable and extensible.

Although SHIP operator is normally an independent enterprise, it corresponds to the site/area level in this information infrastructure from the manufacturing system’s point of view, i.e. SHIP’s function equals to a warehouse plus a fleet. As the operated objects and working logics in SHIP are consistent with those in manufacturing shop floor, the lower levels of AUTOM (the dotted block) will be directly adopted as the real-time production logistics information infrastructure used in this project.
The right part of Figure 2 illustrates AUTOM’s main technical levels. The highest level includes those enterprise information systems (EISs), such as ERP, MES of manufacturers and suppliers. The second level includes those application system(s) developed for the major sites/areas of an enterprise. In this project, the RFID-enabled SHIP JIT logistics system belongs to this level, i.e. materials collection, storage, cross-docking and distribution processes. The two lowest levels form a RFID-enabled smart SHIP logistics environment, including Smart Gateway and Smart Object. AUTOM facilities provide an efficient way for creating a RFID-enabled shop floor. The following subsections will detail the instantiation process.

2.2 Overall System Logic Design

For the suppliers and manufacturers in SHIP, we assume the real-time material consumption or product outputs in their workshops could be obtained from their MES (Manufacturing Execution System) [6]. In the real-time MES, RFID readers and/or tags are deployed to key manufacturing resources, e.g. workstations, trolleys, key components or their containers etc. The flow of production materials attached with RFID tags is tracked and traced, and real-time disturbances during production are detected and fed back to SHIP. Then, SHIP will consolidate the requests and plan the logistics resources to fulfil.
Suppliers’ real-time outputs will generate material collection requests, which will be handled by SHIP’s material collection decision module, see the left part of Figure 3. Milk-run collection tasks are planned and released to operational level (logistics trucks) for execution. With handheld RFID devices, truck drivers could accurately and real-time get and finish their material collection tasks. Collected materials will then be put into the receiving dock of SHIP, and warehousing decision module will plan whether to put away such materials into warehouse or to cross-dock and distribute the materials directly to manufacturers, see the middle part of Figure 3. Similarly, manufacturers’ real-time material requirements will generate material distribution requests, handled by SHIP’s material distribution module. Based on both the material requests and the collected materials from suppliers, distribution decision module will determine the distribution milk run and release to operation level for distribution execution, see the right part of Figure 3. All the RFID-enabled operation process will be detailed in the following sections.

3 RFID-ENABLED SHIP APPLICATION MODULES

3.1 Milk-Run Materials Transportation Module

The purpose of this module is to assist truck drivers to perform milk-run material collection and delivery processes, where multiple suppliers or manufacturers are visited in a single route. Receiving dock, shipping dock, and all pallets in factories and SHIP are attached a RFID tags which contains location and pallet ID. Trucks and forklifts are equipped with portable RFID devices which are used for detecting RFID tag’s information. RFID Handheld terminals are used for supporting truck drivers to collect objects information and operate the transportation job.
A more comprehensive explanation of how the RFID handheld terminal assists truck drivers is given as follows:

1) Get the transportation job

At the beginning, the driver uses a RFID handheld terminal to download a scheduled transportation job. The transportation job information includes a travelling route, destination information, required materials for transportation and its quantity, and required time of arrival. After download the job, the travelling route is listed as seen in Figure 4(1). The driver follows the route to go to the location one by one.

2) Travel to suppliers / manufacturers

The driver can obtain details information about the travelling location such as company name and address, required arrival time, and location for parking as seen in Figure 4 (2). After the driver arrives, the driver requires using RFID handheld terminal to read the location ID in order to confirm arrival. Then, forklift drivers will be informed to perform loading or unloading operation.

3) Get required materials list for loading / unloading

After the driver confirms arrival, the required materials list for loading or unloading will be displayed as seen in Figure 4 (3). Information of this list includes material name, quantity, and the sequence of loading and unloading.

4) Confirm Load / Unload materials

During the loading or unloading operation, RFID tag attached to the pallet will be detected and displayed in the handheld terminal. The truck driver can review and confirm loading and unloading materials are correct. As seen in Figure 4 (4), the loading or unloading pallet ID and sub-quantity will be displayed in the grid. After this operation is completed, the driver can return to the first screen and travel to other locations until the whole transportation job is completed.

3.2 Pallet Loading And Unloading Module

The purpose of this module is to assist forklift drivers with performing loading and unloading pallets in SHIP’s receiving or shipping dock. Pallets are unloaded from trucks to receiving
dock for materials picking process and loaded from shipping dock to trucks for materials delivery process. In loading process, the sequence of loading material is defined in planning process according to the milk-run route. Similar to milk-run transportation process, receiving dock, shipping dock, and all pallets are attached a RFID tags. RFID Handheld terminals are used for supporting forklift drivers to collect objects information and operate the loading and unloading.

![Figure 5. Pallet Loading And Unloading Process](image)

A more comprehensive explanation how the RFID handheld terminal assists forklift drivers is given as following:

1) **Receive loading / unloading notification**

After the truck driver arrival receiving or shipping dock and confirm their arrival, forklift drivers will receive a notification of truck arrival as shown in Figure 5(1). The notification information includes the truck ID and its parking location. Then, the forklift driver can select and confirm a job to start the operation.

2) **Get loading / unloading materials list**

Once the job is confirmed, a list of required materials and its quantity for the forklift driver loading or unloading will be displayed in the screen as shown in Figure 5(2). According to the sequence of the list, the forklift driver can start the loading or unloading operation.

3) **Operate loading / unloading**

After the forklift driver confirm to pick materials, details information including pickup location and destination will be displayed as seen in Figure 5(3). When the forklift driver pick-up a pallet, the pallet ID will be detected by RFID device and recorded in the grid view. The forklift driver can check the loading or unloading progress. After this operation is completed, the driver can return to the previous screen to load or unload other materials until all materials are processed.

3.3 **Put Away Module**

The purpose of this module is to assist forklift drivers with performing placing materials from receiving dock to storage area in SHIP. Activities include material handling, location verification and placement. In the storage area, all shelves are tagged with RFID tags. RFID Handheld terminals are also used for supporting forklift drivers to collect objects information and operate put-away.
A more comprehensive explanation how the RFID handheld terminal assists forklift drivers is given as following:

1) **Get the put-away job**

At the beginning, the forklift driver uses a RFID handheld terminal to download a put-away job. The put-away job, which is planned by warehouse operators, contains information of pickup specific pallets from specific receiving dock to specific storage shelf. All put-away jobs will be listed in the grid view as seen in Figure 6(1). The forklift driver can select and execute a job.

2) **Pick-up pallets**

After confirmed a job, details pickup information will be displayed as seen in Figure 6(2). The forklift driver can go to the location and pick-up the pallet. When the forklift pick a pallet, the pallet ID will be detected by RFID devices. If the pallet is correct, the operation can go on.

3) **Put-away**

After the driver pick-up a correct pallet, the handheld terminal will display the destination as seen in Figure 6(3). The driver then move to the destination and place the pallet on shelf. The location ID will be read by RFID devices and transfer back to the warehouse management system. The warehouse management will update the pallet and location information. The put-away process is completed and the forklift driver can start the new cycle again.

3.4 **Order Picking Module**

The purpose of this module is to assist forklift drivers with performing order picking process which is to move materials from storage area to shipping dock. Similar to previous processes, shelf units, shipping docking locations and pallets are attached with RFID tags. Also, RFID Handheld terminals are also used for supporting forklift drivers to collect objects information and operate order picking process.
Figure 7. Order picking process

A more comprehensive explanation how the RFID handheld terminal assists forklift drivers is given as following:

1) Get order picking job

At the beginning, the forklift driver uses a RFID handheld terminal to download an order picking job which includes list of required materials, location for picking, destination for placing and job due time. All order picking jobs will be listed in the grid view as seen in Figure 7(1). The forklift driver can select and execute a job.

2) Check job details

After confirm an order picking job, the forklift driver can receive a materials and remaining quantity list for picking as seen in Figure 7(2). The forklift driver can select a material to continuous the process.

3) Pick up pallets from storage area

After select a material for picking, the location of selected material for picking will be displayed as seen in Figure 7(3). If the materials is planned to pick from a specific location, it will only display the specific location. Otherwise, the distribution of the selected material in storage area will be displayed. When the forklift driver picks up a pallet, the pallet ID will be detected by RFID device and displayed in the screen.

4) Placing pallets to shipping dock

After the forklift driver picks up a collect pallet, the location for placing will be displayed as seen in Figure 7(4). After placing the pallet in the correct location, location and pallet information will be transfer back to warehouse management system. This operation will be completed until all required materials are prepared.

3.5 Cross-Docking Module

The purpose of this module is to assist forklift drivers with performing cross-docking process which is to move materials directly from receiving dock to shipping dock. Similar to previous processes, shelf units, shipping docking locations and pallets are attached with RFID tags. Also, RFID Handheld terminals are also used for supporting forklift drivers to collect objects information and operate cross-docking.
A more comprehensive explanation how the RFID handheld terminal assists forklift drivers is given as following:

1) Get order picking job

At the beginning, the forklift driver uses a RFID handheld terminal to download a cross-docking job which includes list of required materials, location for picking, destination for placing and job due time. All cross-docking jobs will be listed in the grid view as seen in Figure 8(1). The forklift driver can select and execute a job.

2) Check job details

After confirm an cross-docking job, the forklift driver can receive a materials and remaining quantity list for picking as seen in Figure 8(2). The forklift driver can select a material to continuous the process.

3) Pick up pallets from receiving dock

After select a material for picking, the current location of selected material will be displayed as seen in Figure 8(3). The forklift driver follows the location to pick up a pallet.

4) Placing pallets to shipping dock

After the forklift driver picks up a collect pallet, the location for placing will be displayed as seen in Figure 8(4). After placing the pallet in the correct location, location and pallet information will be transfer back to warehouse management system. This operation will be completed until all required materials are prepared for loading to the truck.

4 A CASE STUDY

A complete case of RFID-enabled milk-run material distribution and collection processes in SHIP will be illustrated in this section. All steps in this case are arranged according to the logical sequence of the involved decision and operation procedures, see Figure 9.
There are two milk-run material processing circles. Left hand side shows the material collection milk-run between SHIP and suppliers. Right hand side demonstrates the material distribution milk-run between SHIP and manufacturers. Each milk-run circle consists of linked decisional activities and operational activities. As shown in the figure, each activity is directly enabled by one of the explore modules downloaded to the corresponding RFID-Gateway or PC while supported by the web services running at the back end. The screen copy and the user of each activity are shown in the block. The activity blocks on higher part are decisional related activities, aiming at making the material planning and resources scheduling decisions. The activity blocks on lower part are operational related activities,
which are responsible for executing the plan and schedule by practical material movement. The details of each activity will be illustrated as follows.

(1) Process of Material Distribution Milk-run

**Step 1 Material Distribution Requests pooling**

In the proposed RFID-enabled milk-run JIT concept, the start of material distribution milk-run is trigger by the material distribution requests from the manufactures. The manufactures in the industrial part are equipped with the RT-MES system. The “RFID-Enabled Inventory Control Point” in the system can automatically monitor the material inventory level and generate material requests based on the predefined safe inventory level as well as the real-time production tempo. The material distribution request should include the required material type, quantity, supplier and expected delivery time interval. All of such requests sent from the “Inventory Control Point” in different manufactures will be received by SHIP and stored in a material distribution requests pool.

**Step 2 Material Distribution Planning**

The material distribution requests stored in the request pool will be coordinated to generate material distribution plans. The distribution order manager in the SHIP will do this work with the support of “Material Distribution Planning Explore”. The aim of this plan is to determine what materials distribution requests should be combined into one milk-run trip. Therefore, object of this plan is the materials stored in the SHIP. The material quantity, size, delivery route and delivery time window should be considered in this plan. The predefined planning rules and algorithm in the distribution order planning web services will help the order manager to make decisions. A material distribution plan determines which and how many items should be loaded in one truck and delivered to which manufactures under what sequence within what time window.

**Step 3 Material Distribution Scheduling**

After the material distribution plan is generated, it will be released to “Material Distribution Scheduling Explore” to make a material distribution schedule. The aim of this schedule is arranging external transportation resources to execute a distribution milk-run trip. Therefore, the objects of material distribution scheduling are the trucks and truck drivers for the delivery between SHIP and manufacturers. The material distribution fleet manager will takes charge this scheduling work. The fleet manager can check the real time status of truck and the shift list of truck drivers with the “Material Distribution Scheduling explore”. In a material distribution scheduling decision, a material distribution plan will be bound to a specific truck and a suitable truck driver will be assigned to execute this milk-run distribution work.

**Step 4 Material Pickup Planning**

When the material distribution plan is released, the material pickup inside the SHIP should start at the same time. This internal material pickup work also can be divided into planning phase and schedule phase. In the planning phase, the material pickup order manager will determine how to get the required materials in SHIP. There are two possible methods for the materials pickup in the SHIP. One is to seek the required materials in the storage area. Another is to get the required materials from the receiving dock directly, which is called cross-dock. Although the cross-dock should be the dominate method of material pickup within a SHIP scenario, materials in the storage area has higher priority to be picked up. Because one of the overall objectives of SHIP is reducing the inventory holding cost. After the method of pickup is determined, the pickup order manager also needs to indicate the exact location of each item. The “Material Pickup Planning Explore” will help the manager
to locate the materials either in the storage area or in receiving dock, and then work out a complete material pickup plan.

**Step 5 Material Pickup Scheduling**

Similar to the Material Distribution Scheduling, the aim of material pickup scheduling is to arrange internal transportation resources and facilities to each material pickup plan. Therefore, the objects of material pickup scheduling is the forklifts and shipping decks. This work is done by material pickup fleet manager and supported by the “Material Pickup scheduling Explore”. Normally, each forklift has a fixed driver during one shift. Therefore, the fleet manager only need to assign the material pickup plan to an appropriate forklift and indicate the exact pickup location of each item. Meanwhile, the ID of shipping dock for each plan should be specified. The determined shipping deck actually is the gather point of all materials in one material pickup plan. Such shipping dock ID will be informed to the truck driver who takes corresponding distribution plan. Actually, the shipping dock ID is a link between material distribution plan and material pickup plan.

**Step 6 Material Pickup Operation**

The material preparation plan and schedule generated by above decision modules will be released to the “Material Pickup Operation Explore” which is available on forklift drivers’ PDA. Since there are two possible locations for materials in the SHIP, two types of operator response for different material movement duty. The first on is called warehouse operator, who takes charge the transportation work between the storage area and shipping docks. The second on is call cross-dock operation. They move the required materials directly from receiving dock to shipping dock. The transportation work of both of warehouse operator and cross-dock operator will be guided by a clear pickup instruction on their PDA. The instruction shows the required material type, quantity and exact pickup location either in the storage area or in the specific receiving dock. The RFID reader equipped on the forklift also can check the tags on the pickup location as well as tags on material pallet to guarantee the operator picking right item from right place. Finally, the materials required in one distribution plan will be picked up and gathered into an assigned shipping dock. When all required materials are ready on the shipping dock, the ID of this shipping dock will be sent to the external transportation truck driver who responses for this distribution milk-run trip.

**Step 7 Material Distribution Operation**

The truck drivers of external transportation are also equipped with personal PDA. They can check and download distributions task with “Material Distribution Operation Explore” on this device. When a truck driver takes a task, his personal information is bound with the assigned truck. Then, he will park the truck to the indicated shipping dock. At that moment, the required materials in this distribution task are already located on the dock. The loading operator on the dock will confirm the Distribution plan ID with the driver firstly, and then the materials will be loaded on the truck with determined sequence, which is based on the distribution route. After the loading work finished, the truck driver can start the Material Distribution milk-run trip. The detailed transportation instruction is available on the “Material Distribution Operation Explore”, which includes the distribution route, materials details and the customer (manufacturers) information. The material transition between the driver and customers is also controlled and monitored by the RFID-enabled PDA system.

(2) Process of Material Collection Milk-run

**Step 1 Material Collection Requests pooling**

Similar as the material distribution process, the start of Material Collection Milk-run is trigger by the material collection requests from the suppliers. The suppliers in the industrial part are also equipped with the RT-MES system. The RFID enabled inventory control points in
the system can automatically monitor their finished product inventory level and generate material collection requests based on the predefined inventory occupancy level as well as the real-time production tempo. The material collection request specifies the material type, quantity, customer (manufacturer) and expected collection time interval. All of such request sent from the inventory control points of different suppliers will be received by SHIP and stored in a material collection requests pool.

**Step 2 Material Collection Planning**

The material collection requests stored in the request pool will be coordinated to generate material collection plans. The collection order manager in the SHIP will do this work with the support of “Material Collection Planning Explore”. The aim of material collection planning is to determine what materials collection requests from different suppliers should be combined into one milk-run trip. Therefore, the object of this plan is the materials distributed in several suppliers. The capacity of collection truck, material quantity, size, collection route and time window should be considered in one collection plan. The predefined planning rules and algorithm in the collection order planning web services will help the order manager to make decisions. A material collection plan should determine which and how many items should be collected from which suppliers under what sequence within what time window.

**Step 3 Material Collection Scheduling**

After the material collection plan is generated, it will be released to “Material Collection Scheduling Explore” to make a material collection schedule. The aim of this schedule is arranging external transportation resources to execute a collection milk-run trip. Therefore, the objects of material distribution scheduling are the trucks and truck drivers for the delivery between SHIP and suppliers. The material collection fleet manager will takes charge this scheduling work. The fleet manager can check the real time status of truck and the shift list of truck drivers with the “Material collection Scheduling explore”. In a material collection scheduling decision, a material distribution plan will be bound to a specific truck and a suitable truck driver will be assigned to execute this milk-run distribution work. In a material collection schedule, a material collection plan will be bound to a specific truck and suitable driver will be assigned to take this material collection milk-run trip.

**Step 4 Material collection Operation**

The truck drivers of external transportation are equipped with PDA. They can check and download distributions task with “Material Collection Operation Explore” on this device. When a truck driver takes a task, his personal information is bound with the assigned truck. The detailed transportation instruction about the material collection will be shown on the PDA, which includes the collection route, materials details and, expected collection time window, the customer (suppliers) information. When the driver arrives a collection point, the material transition between the driver and customers is checked and confirmed based on the PDA system. After the whole collection milk-run trip is completed, the truck will come back to SHIP and park on the specific receiving dock. An unloading operator will stand by on the receiving dock to unload the materials. Meanwhile, the real time material date will be updated. The material distribution schedule system can detect the new arrival materials and arrange the cross dock operation. Through the real time material date on receiving dock, the Material Collection milk run process and Material Distribution Milk run process are linked together.

**5 CONCLUSION**

This paper introduces a RFID-based small-lot and high-frequency JIT production logistics management system. The system makes full use of the RFID-enabled manufacturing execution system (MES) deployed at both supplier and manufacturer side. It develops real-
time execution facilities (explorers) for the key logistics stages of a SHIP-based logistics process so as to facilitate the corresponding operators executing the logistics plan/schedule in a traceable way. Cutting-edge technologies of industrial informatics have been adopted for system development to allow maximum system integrity and scalability, and third-party customizability and usability.

The next-stage plan of this research is to develop the real-time adaptive decision modules which will collaborate with the RFID-enabled logistics operation modules introduced in this paper. By the real-time adaptive decision modules, orders are dynamically split into pieces and consolidated into a sequence of shared logistics tasks which are scheduled based on the logistics resources’ real-time statuses and attuned with the suppliers’ and manufacturers’ real-time production progresses. Then, by the RFID-enabled operation facilities, the materials collection and distribution around SHIP could be collaboratively and accurately executed in a small-lot and high-frequency milk-run mode logistics to achieve WIP reduction for both suppliers and manufacturers.

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7 REFERENCES


