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A framework of data-driven dynamic optimisation for smart production logistics

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Abstract. Production logistics systems in the context of manufacturing, especially in automotive sectors today, are challenged by the lack of real-time data of logistics resources, optimal configuration and management strategies of materials, and optimisation approaches of logistics operations. This turns out to be the bottleneck in achieving flexible and adaptive logistics operations. To address these challenges, this paper presents a framework of real-time data-driven dynamic optimisation schemes for production logistics systems using the combined strength of advanced technologies and decision-making algorithms. Within the context, a real-time data sensing model is developed for the timely acquisition, storage, distribution, and utilisation of equipment and process data in which sensing devices are deployed on physical shop floors. The value-added data enable production logistics processes to be digitally visible and are shared among logistics resources. A multi-agent-based optimisation scheme for production logistics systems based on real-time data is developed to obtain the optimal configuration of logistics resources. Finally, a prototype-based simulation within an automotive manufacturing shop floor is used to demonstrate the proposed conceptual framework.

Keywords: Production logistics, IoT, data-driven optimisation, multi-agent system.

1 Introduction

Production logistics in the context of smart manufacturing aims for flexible and adaptive production and logistics operations by using integrated information technologies that can combine advanced computing power with networked equipment [1][2]. Production logistics systems are multidimensional and complex systems that cover material handling, planning, scheduling, and management of logistics resources and control of manufacturing execution systems [3]. Smart production logistics systems depend on the timely acquisition, storage, distribution, and utilisation of equipment and process data [4], as well as advanced analytic tools [5], amplifying the human ability to improve

productivity and quality in production logistics. The rapid development of manufacturing requires advanced production and logistics strategies in global supply chains. Therefore, there has been an increasing interest in the field of production logistics from both academia and industry. With the advancement of the latest technologies such as the Internet of Things (IoT) and mobile internet [6], production logistics systems used today show the potential of meeting the expectation of Industry 4.0 and smart manufacturing. These technologies will facilitate real-time information sharing, knowledge discovery, and informed decision making [7].

In production logistics, i.e. factory internal logistics, companies are still facing typical challenges that lie in a lack of concrete models used for real-time data acquisition and sharing and digital visualisation of production logistics systems. This has led to the difficulties in monitoring and controlling physical resources on shop floors. Exception events (i.e. failures and breakdown) that may occur on the shop floors cannot be actively sensed and timely handled, which may trigger the rescheduling of logistics resources. Numerous logistics tasks and production demands from upstream and downstream suppliers also call for an efficient resource management system. In addition, the optimal configuration of logistics resources fails induced by the lack of real-time data and optimisation algorithms, which can increase the cost of transportation and material handling. To address such challenges, this paper proposes a framework of data-driven dynamic optimisation for production logistics systems which is for the digital visualisation and optimal configuration of logistics resources. Within this framework, an IoT-enabled real-time data sensing and visualisation model is developed to acquire equipment and process data by deploying sensor networks on the physical shop floor. Digital visualisation of production logistics systems is for the virtual control and management of materials, status monitoring and tracking, and ease-to-use visualisation services on the shop floor. Then, a real-time data-driven dynamic optimisation strategy using multi-agent technologies is developed for the optimal configuration of logistics resources and efficient material handling.

The remainder of this paper is organised as follows: Section 2 describes a real-time data sensing and visualisation model. Data-driven optimisation configuration of logistics resources is presented in Section 3. In Section 4, a prototype-based simulation focused on an automotive shop floor is proposed to demonstrate the proposed framework. Section 5 draws conclusions and highlights future work.

2 Real-time data sensing and visualisation

An IoT-enabled real-time data sensing model for production logistics systems, as shown in Fig. 1, is developed for the timely acquisition, processing, and utilisation of production and logistics data in which smart devices are deployed on the physical shop floors. Through the use of acquired data, digital visualisation of production logistics systems is designed to offer end-users easy-to-use services of production status, logistics planning, and path navigation. In this model, it consists of three modules, i.e. configuration of smart devices, sensing and processing of data, and visualisation.

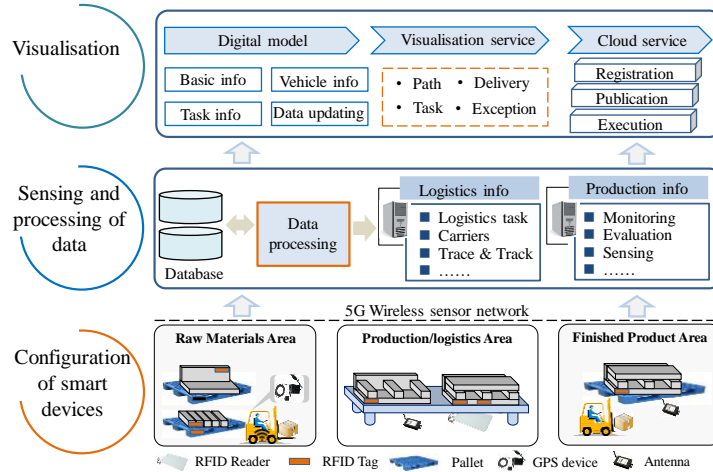


Fig. 1. A real-time data sensing and visualisation model for production logistics systems.

Configuration of smart devices is used to deploy smart sensing devices/sensors on the physical shop floors such that a sensing environment can be developed where production equipment/logistics resources can be monitored, tracked, and traced. The physical shop floor is classified as a raw material area, a production/logistics area, and a finished product area. For each area, Radio-frequency identification (RFID) technologies [8] are applied to sense and capture the real-time information of logistics resources, production processes, and WIP (Work-in-Progress) inventories. RFID readers installed with antennas are used to capture the production/logistics items attached with RFID tags. For example, when an item passes through the sensing area embedded with sensor networks, this event can be timely sensed and the information of this event is acquired. Then, the real-time status of this item can be monitored and traced. A real-time location system of transportation carriers on the shop floors is developed where the real-time location information acquired is used for the dynamic optimisation of the production logistics system. For the production/logistics area, external interfaces of some devices allow to get access to machining/assembling progress, and the traceability and monitoring of raw materials and WIPs make the status of buffers between devices transparent and visible.

Using 5G wireless sensor networks, real-time data acquired from the physical shop floor are transmitted to the module for sensing and processing of data and stored in the dataset. These data can match the specified events on the shop floor and they can be defined as a form of events, e.g., basic, complex, and key events. A basic event contains general information of production/logistics items (e.g., event ID and temporal and spatial attributes). The information included in a complex event reflects the status updating of logistics resources and production processes. A key event defined in the production logistics system impacts the overall performance of the system (i.e. production exception and urgent task delivery). The event-based data processing model simplifies the classification and management of primitive data. For the logistics module, it contains logistics task plans, real-time information of logistics tasks and carriers, delivery lists

of tasks, and path plans. Within this module, an information updating approach is developed to synchronise the change of logistics tasks and carriers in terms of volume, weight, location, and delivery lists. The production module has the information of production/assembly plans, monitoring status of production equipment and buffers, and evaluation of production/assembly progress.

Then, the digital visualisation of the production logistics systems is to offer end-users user-friendly digital services, which includes a digital model, visualisation services, and cloud services. The digital model is for developing a digital platform used for data encapsulation, digitalisation, and management of logistics/production resources where an object-oriented Java programming language is used to encapsulate information and create a web-based information management platform. Within this digital model, real-time data of logistics tasks and carriers and production/assembly processes are digitalised via a modular combination of interfaces, and display, query, invocation, and editing of data can be performed by users via a human-computer interface. The visualisation services are of importance for operators to perform tasks/operations in which path plans and navigation of carriers, lists of tasks, delivery status, and exception events can be digitalised. These available services can be embedded and displayed in a portable mobile device. A typical example is that a delivery request of logistics tasks can be displayed to instruct operators to perform related operations. In addition, exception events (i.e. errors of task delivery/loading) can trigger a signal alarming to eliminate operator-made mistakes. Cloud services offer opportunities for extendable applications across the whole production logistics network.

3 Data-driven optimisation configuration of logistics resources

In this section, a data-driven dynamic optimisation strategy using multi-agent technologies is presented for planning, scheduling, and allocation of logistics resources based on the collected data from Section 2 as shown in Fig. 2. A logistics resource module is for management of logistics resources and offering data input for a multi-

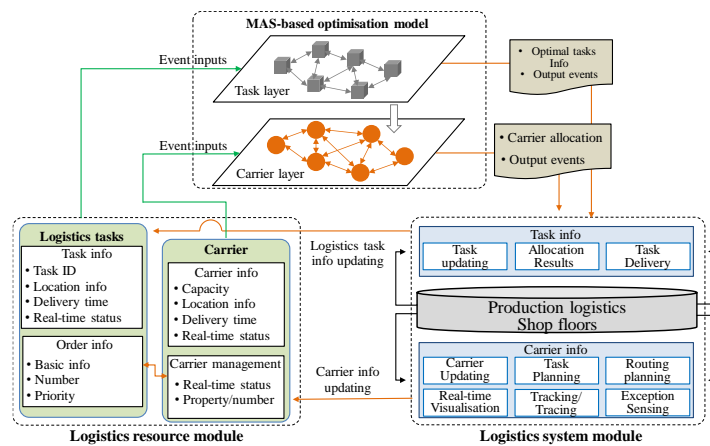


Fig. 2. A conceptual framework of data-driven dynamic optimisation for logistics resources.

agent-based hierarchical optimisation model with constraints. Then, the output results are sent to and stored in a logistics system module where the status of the shop floor can be monitored and digital logistics services can be built. Updated logistics data (i.e. new tasks and exceptions) from the logistics system module are transmitted to the logistics resource module. Then, a closed-loop dynamic optimisation scheme for logistics resources is developed by integrating the blocks of monitoring, scheduling, optimisation, and digitalisation into the production logistics system.

A production logistics system that focuses on a factory-internal part of logistics is to deliver tasks efficiently and effectively to machines/workstations within a highly dynamic environment where unpredicted events that may occur can be prevented. For this purpose, algorithm-driven negotiation and communication among tasks, carriers, and workstations (or machines) are essential. Agent technology is considered as a promising approach used for dynamic optimisation for production logistics [9] and a network of agents, will create a multi-agent system (MAS) whose members not only are responsible for satisfying their local objectives, but also can interact and cooperate with each other to satisfy a global objective. Using the real-time data sensing model, factory-internal logistics resources that have the main characteristics of an agent [10] can be defined as agents. The factory-internal part of logistics prioritises accurate logistics material delivery to ensure the runtime of production lines while minimising logistics cost and improving the efficiency of production logistics systems. Within this context, a multi-agent-based architecture is presented as shown in Fig. 3(a), and interaction and communication of agents (as shown in Fig. 3(b)) are introduced as follows.

- Task agent (TA): consists of all the data of a logistics task; announces task re-

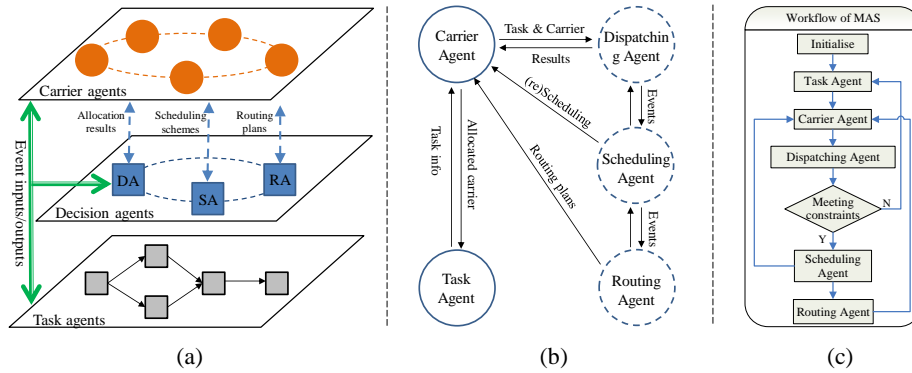


Fig. 3. (a) A hierarchical architecture of MAS; (b) Interaction and communication of agents; (c) A workflow of MAS.

quests in the system; communicates with DAs for carriers' allocation; confirms the task distribution with a CA. A TA is created for a task after the elaboration of a task delivery request and removed from the system when the task is completed.

- Carrier agent (CA): includes all the information of a transportation carrier; interacts with DAs for the assignment of logistics tasks satisfying constraints; confirms the allocated tasks with the TA; communicates with the RA to execute path plans without traffic conflicts; performs the scheduling instructions from the SA.

- Dispatching agent (DA): is embedded with complex algorithms used for the optimal configuration of tasks and carriers where the execution of optimisation algorithms is triggered by the event inputs of TAs and CAs; selects and assigns logistics tasks to the CAs. Dispatching strategies are divided into: (1) workstation-initiated operations and (2) vehicle-initiated operations, depending on whether the system has idle vehicles (vehicle-initiated) or queued transportation requests (workstation-initiated).
- Routing agent (RA): is embedded with dynamic routing algorithms; makes routing decisions based on real-time information; outputs specific paths that each carrier will execute to accomplish its transportation tasks; interacts with the CA to offer path instructions.
- Scheduling agent (SA): is embedded with real-time scheduling algorithms; monitors and manages the entire scheduling process in interaction with other agents; is encapsulated with a reactive mechanism that triggers a rescheduling in case of failure of scheduling plans and handles unexpected events; outputs scheduling instructions.

An event-based communication protocol between agents is adopted for interaction and collaboration according to the definition of event-based data structure in Section 2. When triggered by input events, the agent will start tasks/operations execution by activating the embedded algorithms/behaviours used for task allocation, routing planning, and scheduling planning. Finally, when the task is finished, the agent's event output will send triggering signals to related agents. The procedures of a MAS-based scheme, as shown in Fig. 3(c), are summarised as follows:

- Step 1: initialise TAs and CAs by the input events from the logistics resources module.
- Step 2: send the output events of TAs and CAs to trigger DAs.
- Step 3: DAs perform embedded algorithms and assign the optimal logistics tasks to the carrier.
- Step 4: create communication and matching between TAs and DAs.
- Step 5: RAs triggered by the event inputs from the CAs send the optimal routing plan to the CAs for the task delivery.
- Step 6: SAs triggered by the input event from the TAs and CAs monitor the scheduling process until the finish of the task delivery.

The output results of the multi-agent-based dynamic optimisation model are classified as the optimal tasks and carriers. The optimal tasks are depicted with a task set which contains the allocated carriers, and a carrier set that contains logistics task lists, routing plans, and scheduling instructions is created to instruct the logistics task delivery. These output results are sent to and managed in the logistics system module as shown in Fig. 2. A submodule of task information is for task updating initiated from carrier/workstation sides, managing the allocated task results, and monitoring task delivery, and a submodule of the carrier is for carriers' status updating, managing task plans and routing plans, offering digital visualisation services, and handling task delivery and exception. Then, data of these two submodules are stored in the database used for the historical task tracking.

4 A prototype-based simulation

This section introduces a prototype-based simulation within an automotive manufacturing shop floor as shown in Fig. 4. Digital services designed aim for data visualisation of elements and monitoring and managing the production logistics systems on the shop floor, which offers easy-to-use interaction with operators. Function tabs located on the top of the visualisation interface are designed. *Home* tab allows an operator to create/logon an account and external interfaces to be connected for extended functions/services. This enables the traceability of the operations performed by operators. *Task IF* and *Carrier IF* are used to show real-time data of the tasks and carriers registered on the shop floor. *Path plan and navigation* is to show the path results optimised by the embedded algorithms and offer the path navigation services for the carriers. *Shop floor* is to show and monitor the real-time status of the shop floor, i.e. machine and buffer status, machining progress, inventory information, and exception events. *Bulletin* is to show instructions and event information when clicking on the tab including data of tasks and carriers, task demands, and exception events from the shop floor. Re-scheduling/re-navigation will be performed followed by the optimisation triggered by exception events.

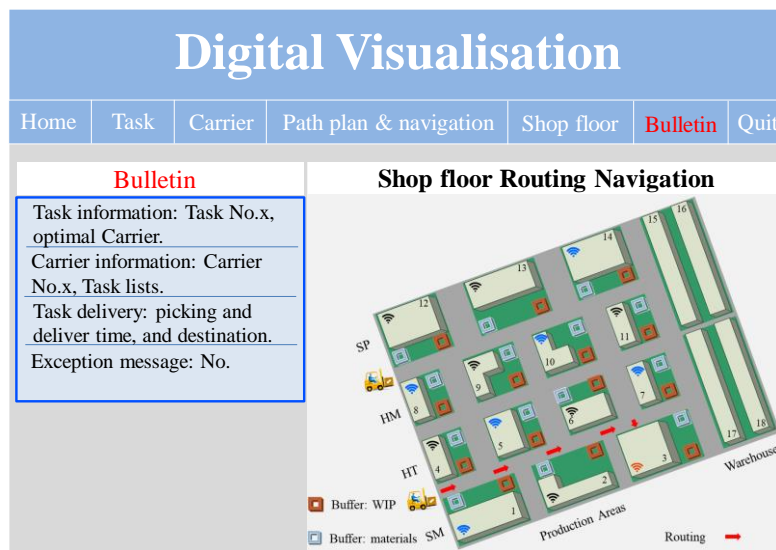


Fig. 4. A prototype-based simulation and digital visualisation.

A use case focuses on a factory-internal part of the shop floor in an automotive manufacturing company, which consists of a warehouse, two transportation carriers, and a production area for soft machining (SM), heat treatment (HT), hard machining (HM), and shot peening (SP) as shown in the right side of Fig. 4. Machines and buffers are defined as a numbered workstation cell that can trigger the workstation-initiated dispatching requests. The signals marked on the workstation show the varying priorities

of task demands with different colours. Within the sensing and communication network in Section 2, the real-time status of elements on the shop floor can be sensed and monitored. Then, the event inputs of tasks and carriers trigger the runtime of the MAS-based optimisation approach, which sends output events. The output results are transmitted to the carriers and displayed through the digital visualisation interface. Finally, the path plan marked by red arrows is used to directly navigate operators to finished the task delivery, which can avoid the time-consuming path search.

5 Conclusions

This paper proposed a framework of data-driven dynamic optimisation for production logistics systems, aiming for the optimal solutions of logistics resources configuration. Within this context, a real-time information sensing and visualisation model was developed for timely acquisition, processing, and digital visualisation of production and logistics data. Then, a data-driven optimisation configuration scheme for logistics resources was presented for planning, scheduling, and allocation of logistics resources in which multi-agent technologies are adopted. Finally, an industrial case study focused on an automotive factory-internal part of logistics is carried out to illustrate the proposed framework. Our future work will focus on advanced algorithm development for real-world complex industrial practices.

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