WITPO: A System for Tracking and Optimization of Work-in-Progress Inventory

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Abstract
Manufacturing companies have embraced Internet of Things and data analytical technologies to optimize manufacturing processes. In a typical case, they benefit from having a controlled environment with well-structured workflows and established facility layouts. However, production of highly customized products and organization of shop-floor operations remains a challenge. This project investigates the problem of work-in-progress inventory management in the case of on-demand production of customized products having a multitude of production workflow variants and a significant share of human operations. It aims to create an information system, which uses Internet of Thing to track movement of work-in-progress inventory and optimizes materials picking and placement. The computer vision is used to reduce the need for materials tagging and spatial database technologies are used to create a dynamic view of the shop-floor layout taking into account current locations of work-in-progress inventory. The system can be customized for various manufacturing facilities. The project is carried out in a university industry collaboration involving companies specializing in industrial Internet of Things. The system is tested at a medium-sized printing company.

Keywords
Industry 4.0, Internet of Things, work-in-progress inventory, process optimization

1. Introduction

Large manufacturing companies have achieved a high degree of automation in running of their operations courtesy of integration between Enterprise resource planning (ERP) and Manufacturing execution systems (MES) [1]. However, information systems used by small and medium size companies often lack sophistication of the advanced systems or do not have sufficient scale to invest in complex digital technologies [2]. Current developments in information technology allow smaller companies to deploy modularized solutions for

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specific value-added process [3]. This project specifically considers the problem of Work-in-Progress (WIP) Inventory Management (IM) at a printing company. WIP inventory are materials and intermediate products stored on the shop floor close to manufacturing equipment to await the next production step. The materials are picked up to set up the next production step, and intermediate products obtained as the result of the production step are placed at a suitable location for further processing. These operations can be performed at different levels of automation. Technologies such as Radio-frequency identification (RFID) are often used to facilitate the WIP management operations [4]. The problem at hands is characterized by on-demand production, material and location tagging restrictions, large-product variety, limited WIP inventory storage space and dynamics shop-floor layout (i.e., pick-up routes are affected by the current placement of WIP inventory).

The project goal is to develop a modular and extensible system to optimize WIP IM for custom on-demand manufacturing processes. The novel features of the system are 1) combination of Internet of Things including computer vision to track movement of WIP inventory, 2) dynamic representation of the layout of manufacturing facilities and 30 optimization methods to generate optimal WIP inventory pick-up routes and suggests placement of the intermediate products on the shop-floor. It is ought to be integrated with the core enterprise resources planning system and the sensing infrastructure established could be used for optimization of other manufacturing processes including digital twin development. The project furthers the field of information systems engineering by co-designing intelligent data processing system and optimal decision-making algorithms with balanced allocation of computations between edge and cloud computing. This paper reports the current results with focus on requirements elicitation and high-level architectural design. The project furthers

The project is carried out by consortium of Riga Technical University and two information technology consulting companies as well as by a printing company providing testing facilities. The project is funded as a part the Competence Centre of Information and Communication Technologies program in Latvia what fosters implementation of innovation projects in industry. The rest of the paper is organized as follows. Section 2 reviews related work on warehouse management. The overall project information is provided in Section 3. Business process analysis is presented in Section 4. Section 5 introduces the architecture of the WIP IM system and Section 6 concludes.

2. Related Work

The WIP IM optimization system referred as to WITPO is developed on the basis of the state-of-the-art of computer augmented warehouse management. There is a large number of inventory and warehouse management processes such as materials receiving, placement, storage, picking, packing and shipping [5, 6], and this project addresses warehouse layout planning, information availability, location planning and routing to pick-up materials. Empirical evidence suggests that material pick-up is one of the most time-consuming operations [7], and real-time data are need for efficient routing [8]. RFID tags are the most commonly used materials tracking technology, and it requires tagging materials themselves, pallets, trolleys or tracking gates [9]. The overall materials tracking and operations management systems has the following components: IoT component for data gathering, data processing module for identifications of materials, planning module and execution module [10]. Further research [11] supplements these components with a machine learning component to analyze custom movement trajectories taken by production operations. Edge devices such as self-guided carts use infra-red light to avoid collisions and RFID for tracking [12]. The MQTT protocol ensures moderate data exchange reliability of 80%. IoT technologies are often used in smart shopping to identify products and their movement [13]. A closely related study [14] focuses on digitalization of printing processes and proposes a business process management approach to optimize the manufacturing processes. Robots are used to perform manufacturing steps and AGV are used to pick-up materials. The technologies are deployed in a laboratory environment and both advantages and shortcomings are assessed.

The current methods are well suited for materials identification and pick-up routes optimization in facilities with regular layout. The WITPO project focuses on facilities with irregular layout, which dynamically changes.

3. Project Plan and Partnership

The project follows a waterfall approach. This approach is selected because the project was proceeded by a feasibility study. The feasibility study established key requirements and proposed high level design of the envisioned solution. The project concerns WIP IM in the production environment. A production operator receives information about production orders what includes a list of materials required to produce an end-product. Sensing technologies such as computer vision and RFID provide data on location of the materials. These data are aggregated and processed to create a materials pick-up route, which is executed to set-up a production step. The production step yields an intermediate product, which should be placed in suitable location on the shop-floor for the next production step.

The current project consists of: 1) Requirements and design phase; 2) Implementation phase; and 3) Field testing phase. The project is relatively short (one and half years) and every phase is six months long. The system design was performed using the C4 method (see section 5). This method is well-suited to develop modularized systems and to allocate work to partners responsible for specific functionality. The project is carried out by four partners: 1) Riga Technical university – an academic partner responsible for the overall design and optimization; 2) Will Sensors – an industry partner working in the area of industrial IoT and responsible for development of object identification techniques; 3) Data Group – an industry partner developing edge-cloud solution and responsible for the system integration and deployment; and 4) A printing company – participates in defining requirements and provides facilities for the field study. The implementation phase includes two parallel traits, namely, a) development of WIP inventory optimization model; and b) implementation of the platform services. The implementation and field testing leads to the TRL7 level. Testing is carried out in a test environment and several iterations are envisioned to tune accuracy of sensing technologies. The final evaluation will be performed at the printing company' s facilities. It will focus on accuracy of identification of materials as well as efficiency of WIP

IM. It is aimed to strike a balance between investment in sensing equipment and performance gains in IM.

4. Business Processes Analysis

To define WIP process optimization areas, the case company is investigated. Existing business processes were defined, along with the potential improvement areas. Consequently, the initial requirements to the WITPO system were defined.

4.1. Case Company

The project is motivated and will be tested by the needs of a case company, a small and medium size printing company (further referred as JTI). The company specializes in printing of high quality books, diaries, advertisements and similar products. The number of books printed was 4.5 mill. in 2020. The company has about 155 employees. The company performs an end-to-end printing process on paper sheets. The state-of-the-art computer controlled machinery is used in the production. Still, the process requires continuous supervision by workers and a certain number of manual operations. The workers' skills and performance significantly affect production efficiency and quality. During the study, researchers analyzed the company's production processes as well as interviewed production managers and information technology specialists and conducted field visits.

There are 900-1000 WIP items on any given day. The IM system supports registration of components of unfinished products and finished products. Operators have difficulties to locate the WIP items and to locate the most suitable location for newly arriving product component palettes. The aim is to reduce the time operators spend on non-value-added operations such as locating WIP items and most suitable free storage spots and to determine the optimal placement of WIP palettes.

4.2. Existing business processes

JTI existing inventory and warehouse management processes were analyzed, using field observation and semi-structured interviews methods. The analysis encompassed two business processes observation visits in the JTI manufacturing premises. In the first visit, preliminary processes were discussed and drafted. The open questions were identified and discussed in the second visit of the JTI. Afterwards the final business processes diagrams were prepared. The primary activities of the process involve receiving orders from customers, preparing manufacturing plans, gathering materials, production, and managing the location and movement of materials and WIP.

The primary roles engaged in the process include *the project manager*, *planner, operator*, *warehouse agent* and *laborer. The project manager* is the primary contact point for the customers, they discuss the order, agree on delivery dates and register the information into the system for planning. *The planner* is responsible for the orders collection and manufacturing plan preparation for each machine. The plan is prepared for 1-2 days and might be changed on a daily basis. The *operator* performs work on the manufacturing facilities. The warehouse agent is in charge about materials issuing and record keeping.

While the *laborer* is engaged in various support tasks, such as assisting with assembly or production processes, handling materials and others. One of the main responsibilities of the *laborer* is to move and re-move inventory, considering the available space in the manufacturing facility and the locations of subsequent processing machines. WIP movement and re-movement can be performed several times per day.

While observing and analyzing business processes, several potential areas for improvement were identified. (1) Low value adding and time-consuming activities in the movement of WIP inventory. A specific role is designated for inventory movement and re-movement throughout the day. Time is consumed in locating WIP inventory as WIP location data is not tracked. (2) Insufficient level of automation and information exchange between the people, systems and machines of the manufacturing line, for example, produced items, time spent. (3) Limited data analysis possibilities. The main information is processed in spreadsheets or even paper form documents, such as notes in the order bags, stickers with order numbers. Additionally, the order status information is not tracked based on the available information from the devices. Furthermore, there are no available means to measure the effectiveness of business processes.

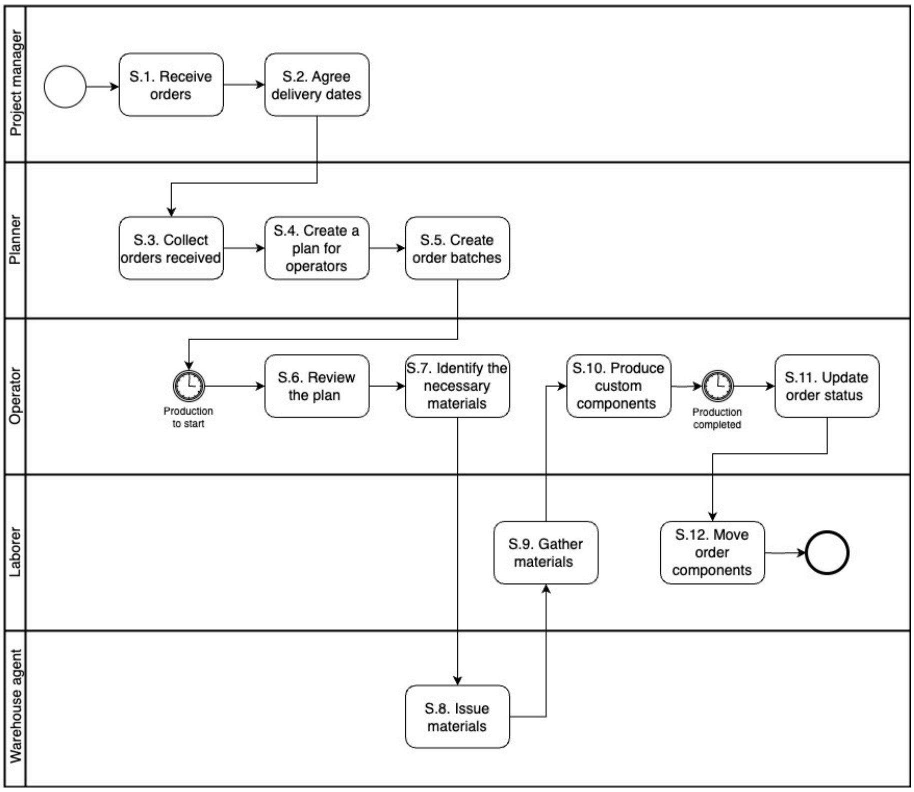

Figure 1: Overview of the JTI manufacturing process.

4.3. Requirements for business process improvement

The business process analysis yields key requirements towards the WITPO system. From a functional perspective, the system aims to improve production steps (steps S.6. – S.10. Figure 1). The main focus is on more efficient identification, location and optimal placement of WIP inventory, resulting in time savings and reduction of low value adding activities (steps S.9., S.12.). According to the interview with the JTI representatives, in the high season, these activities raise significant waste [15], including waiting, non-utilized potential, motion and extra processing. The requirements are defined as user stories and appropriately prioritized. Besides the functional requirements, WITPO non-functional requirements have been defined, considering the common software quality criteria such as functionality stability, performance effectiveness, reliability, maintainability and others.

5. Technical Architecture

The technical architecture is developed using the C4 method following the gradual elaboration starting with the landscape diagram (level 0) to component diagrams (level 3), which could be furthered during the detailed design. The landscape diagram (Figure 2) shows all key systems relevant to the WIP IM. The WITPO is created as a cloud-edge computing system. The WITPO portal is a central cloud-based system providing access to the core functionality. The edge system is responsible for locating materials. Edge devices such as cameras and RFID tags provide raw positioning data. The WITPO portal interacts with the external ERP system, which manages production orders and provide information to WIP IM. The context diagram (referred as to Level 1 in C4) zooms in on a particular system of interest. It is created for the WITPO portal and the edge system separately (not shown). The context diagrams are further elaborated using container diagrams (level 2).

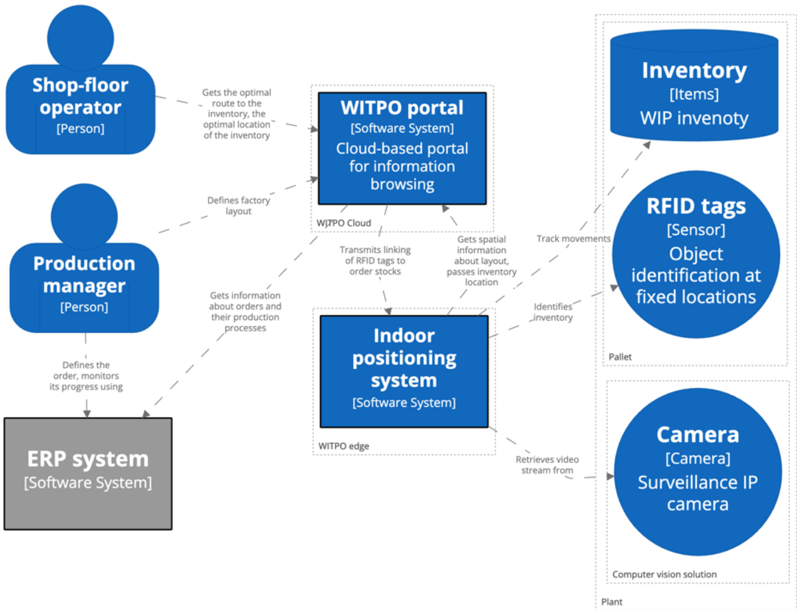

Figure 2: The landscape diagram of the WITPO system.

A container is a separately runnable/deployable unit that executes code or stores data [16]. The Container diagram (not included in the paper) shows the high-level software architecture and distribution of responsibilities. It also shows the major technology choices and how the containers communicate with one another. There are two major points of interaction: 1) Web application accessed using mobile devices by shop-floor operators; and

2) GIS based desktop application for production managers. The key feature of the WITPO solution is representation of the dynamic layout of production facilities caused by placement of the WIP inventory. The data management sub-system is responsible for spatial data management and dynamic regeneration of the current layout. It also provides a possibility to determine distances between points on the shop-floor needed for the optimization algorithm at the database level. The users can view the current positioning of the WIP inventory what is provided by the indoor positioning system. The optimization and routing subsystem generates inventory pick-up routes and suggests placement of intermediate products obtained in manufacturing process. These are displayed to the production operator using the web application accessed using mobile devices. The integration sub-system facilitates data exchange between other systems including production order data exchange with the external ERP system and WIP inventory movement data store in the data management subsystem.

Every container defined in the container diagram is further elaborated in the component diagram. For instance, the Web application has the map component displaying a spatial representation of the production facilities. It shows both static (i.e., manufacturing equipment) and dynamic (i.e., WIP inventory) objects. The Inventory search and pickup routing component helps the operators to locate inventory and delivers instructions for efficient pickup of the required materials. The Inventory placement component displays recommended inventory placement locations after completing the manufacturing step.

6. Conclusion

The paper introduces an industry-university collaboration innovation project developing a new system for WIP IM. The main distinctive features of the proposed system are inventory pick-up routing and placement with respect to dynamic spatial representation of the production shop-floor, distribution of analytical features between edge and cloud nodes and utilization of computer vision to minimize tagging of materials. These features allow to use the system for on-demand production in production facilities having irregular and dynamically changing shop-floor layouts as well as to extend system for various applications relaying on sensing and real-time data processing.

The project is currently in its requirements and design phase. The requirements analysis shows that both current research and practice focus on isolated treatment of WIP IM. However, a more holistic approach considering integration with other production processes and IT infrastructure management might yield further performance improvements. The C4 design method is used in this phase. That allows creating a modular system, and implementation activities can be allocated to responsible parties. The evaluation in the field testing phase will focus on finding the right balance between materials identification accuracy as needed for accurate routing and investment made in the sensing infrastructure. The computer vision will be prioritized because of its greater flexibility and traditional RFID technologies will be used as supplementary tools to improve the accuracy.

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