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QR code-based material flow monitoring in a subcontractor manufacturer network

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Abstract

Principal manufacturers suffer from uncertainty as they lack up-to-date information on their orders in supply chains (SCs). The current era of digitalization offers many solutions to monitor order statuses through integrated information systems. However, the requirements to implement such systems are high for the companies and they still prefer personal interactions with suppliers. This paper proposes a QR code-based order monitoring system in a subcontractor manufacturer network. The objective of the study is to assess the technological and operative maturity of the system in real SCs. A prototype system was built and demonstrated to representatives from Finnish companies in a virtual workshop. The feasibility study showed that the QR code-based monitoring system is practical and promising. The companies, however, recognize that its implementation would be challenging from both the technical integration and subcontractor adaptation points of view. The results obtained give insights into modern information management in SCs and suggest areas of interest for further studies.

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Keywords: supply chain; subcontractor manufacturer; monitoring; QR code; feasibility study

1. Introduction

Production management in a subcontractor network is problematic, especially in the project-oriented business. For example, one Finnish company (turnover 100 MEUR) has 80,000 purchase order lines per year, of which 5000 are open all the time at hundreds of suppliers. Controlling such a huge number of open order lines is practically impossible. Traditionally, a contract is made with suppliers or subcontractor manufacturers to assure good delivery performance. A lot of manual work is required to get information about the statuses of orders, as companies still prefer personal interactions with suppliers [1]. Nevertheless, a subcontractor network continually faces different kinds of problems, resulting in less than 100% delivery performance.

As the situation described above is common in manufacturing companies, one may ask how this can be

managed better. In the current era of digitalization, supply chain (SC) monitoring could increasingly take place through internet-based information technology (IT) systems [2]. Even though companies' key concern is a lack of visibility in their SC network, they do not see the immediate benefits of such systems [1]. The efforts to implement the systems fail if organizations cannot exchange the most crucial and accurate data necessary for suppliers and customers [1]. Data exchanged in SCs are typically related to ordering, production, transport, and warehouses [3]. For principal companies, perhaps the most important [4] but least accurate data are the statuses of orders in suppliers' production. The implementation of IT-based traceability in SCs should consider all the necessary requirements [5] with appropriate technologies [2,6].

This paper develops a QR code-based material flow monitoring system in a subcontractor manufacturer network. The prototype of the system was constructed and demonstrated

to representatives from Finnish manufacturing companies. The feasibility of the QR code-based system was evaluated through a virtual workshop and a questionnaire. The ultimate purpose of the study is to assess the technological and operative maturity of such system in real SCs and gain insights into areas of interest for future research.

The remainder of this paper is organized as follows. Section 2 introduces the theory on traceability and reviews the requirements, potential technologies, and existing literature on order monitoring in production and SCs. Section 3 presents the prototype and feasibility study of the QR code-based material flow monitoring system. Section 4 provides managerial implications. Section 5 draws conclusions and suggests some areas of interest for further study.

2. Requirements and technologies for order monitoring in production and SCs

The ability to verify events, or traceability, was integrated into the ISO 9000 quality standards about three decades ago and received increasing attention as a manufacturing risk management tool [7]. Especially in logistics, traceability is a commonly used term that integrates both tracking (monitoring) the status and tracing (acquiring improved transparency of) the previous steps of orders in the SC [5]. It is predominant in the food and agriculture industry because of regulations but is becoming more popular in other industries, alongside the adaptation of modern Industry 4.0 practices [8]. Traceability across the entire SC combines both internal and external traceability [8]. Internal refers to keeping records of a product (or order) within a single production process and external refers to the movement of a product between multiple traceability partners or companies. The Global Standards One (GS1) traceability standard [9] defines the level of traceability on the basis of identification precision and logistical hierarchy (Fig. 1) [8].

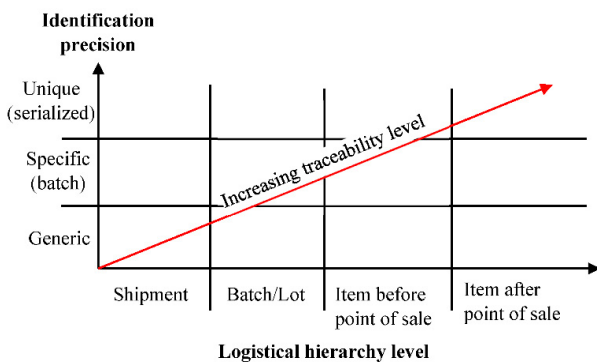


Fig. 1. Traceability levels based on identification precision and logistical hierarchy [8].

This study focuses on material flow monitoring in a make-to-order (MTO) and engineering-to-order (ETO) subcontractor manufacturer network. The products are not standardized but are either configured from the catalog, customer-tailored, or engineered and manufactured on the basis of specifications from the principal company. Thus, they fall into the unique or

specific identification precision category in Fig. 1. The implementation of traceability in SCs requires the following requirements to be fulfilled [5]:

- every object involved needs to be identified precisely to accomplish recognition of the products and components used;
- related data (information) must be collected, associated with the objects, and archived in order for data to be accessed at any time;
- data related to the same object need to be linked to identify coherences between several process steps;
- the whole SC needs to be integrated to avoid redundant data storage and inconsistencies.

2.1. Identification technologies

Product/component identification in a production workshop can be enhanced by advanced technologies [6]. Table 1 assesses the suitability of such technologies in this study.

Table 1. Suitability (***) is the best) of the different identification technologies for the present study.

Technology	Suitability	Why not suitable?
Optical character reader [5]	*	Text format conversion only
Barcode [10]	**	Little data, slow transmission
Quick Response (QR) code	***	
Magnetic strip, Chip card [5]	*	Not for challenging process conditions
Radio Frequency Identification (RFID)	***	
Bluetooth, Wi-Fi [10]	*	The effective range is too small

QR codes and RFID are popularly applied in production workshops as their electronic components are adequately protected inside, and they have corresponding accessories [10]. The RFID is often more cost-efficient in labor-intensive manufacturing as its reading form is one-to-many, whereas a QR code is read one-to-one [10]. RFID requires specific readers (smartphones do not have enough power to generate the strong electromagnetic field RFID requires) and factory-level middleware to which the readers are connected. This middleware is further connected to a cloud server through which the communication is transmitted and where the data are stored. The cost of RFID favors the selection of the cheaper QR codes, by means of which reading can be done using free software and labels are changeable and easily printed at a low cost [11].

Given the importance of the visibility and monitoring of SCs, relatively few studies report monitoring systems and even fewer in the context of SCs involving manufacturing subcontractors. Guo et al. [12] constructed an RFID-based system to access real-time sales information at retailers. Ergen et al. [13] examined the impacts of RFID in the current SC of prefabricated concrete panels. The results from their simulation study showed that the total cost benefit of the panel manufacturer is about twice as much compared to the benefit of

the contractor. The benefits were related to decreases in task durations, in the number of incorrectly shipped or identified items, and in the number of missing panels and reduction of reproduction costs. The study did not consider the benefits arising from monitoring the order status.

2.2. QR code-based monitoring systems

The simple technology and advantages of QR codes attracted monitoring applications in several industries and areas (Table 2). Tavares et al. [14] proposed an architecture for QR code-based SC management, which is also adopted in the system developed in the next section of this study. Kim and Moon [15] developed a QR code-based management system for MTO production. The system enables workers to monitor production information and progress in real time, thus replacing the old methods of Excel records and weekly meetings. Okumura et al. [16] showed that the implementation of QR codes in a Kanban production system significantly improved customer service performance. Other systems provide consumer-accessible product information in SC to support their purchase decision [17,18]. An example of the highest level of traceability, product consumption monitoring at the end user, is the QR code-based monitoring of the medicine intake of patients [19].

Table 2. Previous studies with QR code-based monitoring systems

Reference	Industry/area	Application
Tavares et al. [14]	Not specified	SC management
Kim & Moon [15]	Manufacturing	Process status monitoring
Okumura et al. [16]	Manufacturing	Performance improvement
Tarjan et al. [17]	Food	Product SC tracing
Peng et al. [18]	Food	Product SC tracing
Navin et al. [19]	Healthcare	Medicine intake monitoring
Ćopić et al. [20]	Textile	Human error prevention
Agrawal et al. [21]	Textile	Secure traceability of SC
Qing [22]	Power supply	Defect management

3. QR code-based order monitoring system in a subcontractor manufacturer network

This section proposes a QR code-based system for order monitoring in a vertical subcontractor manufacturer network. Subcontractors deliver MTO and ETO parts and subassemblies for final assembly at the principal company. Fig. 2 illustrates order information management in the network. Each customer project involves purchasing orders which define the suppliers of specific customer orders. The customer order may comprise several purchasing order rows, each of them for one type of item. An order row further defines the factory of a specific item/product and planned delivery time. One order row may comprise multiple production orders, each of them with a predetermined delivery time and number of items.

3.1. System prototype and demo video

Fig. 3 illustrates the technological structure of the system. The blue dotted line area indicates the prototype built on top of

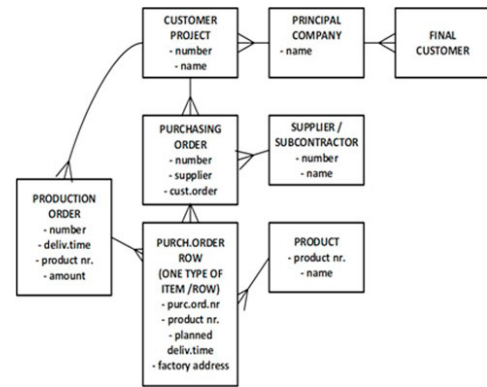


Fig. 2. Order information management in a subcontractor network.

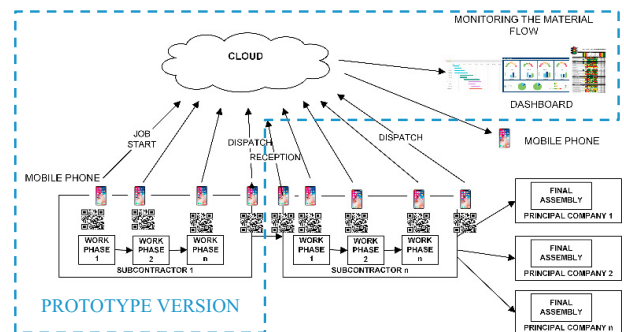


Fig. 3. Technological structure of the QR code-based monitoring system.

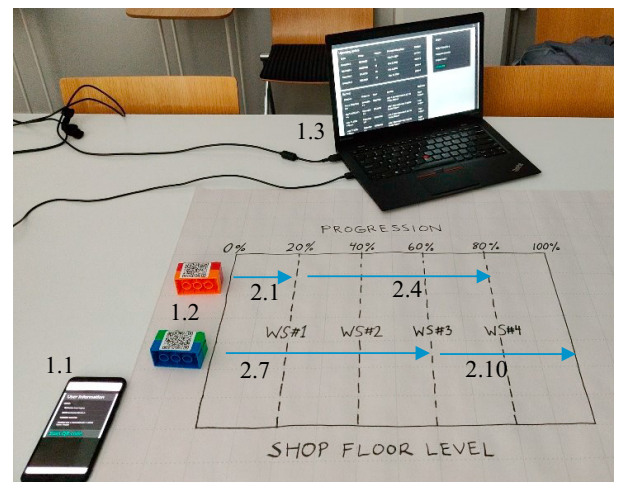


Fig. 4. System prototype (system description (1.1-1.3) and operation (2.1-2.11) video steps are described later in this section).

the table in this study (Fig. 4). The prototype consists of the following technical specifications:

- two Lego bricks representing two orders (rows) with QR labels (36 x 42 mm) printed with a Seiko SLP 650;
- QR code, including project name (8 char.), principal company name (8), subcontractor name (8), delivery date (dd.mm.yy), part name (8), order no. (8), and order row no. (8). Each order row in QR code format contains a short one- or two-letter-long label and a string value separated by a

colon. Each label corresponds to a field of information in the data model of order or order row;

- Django, a python-based, free, and open-source server, that uses Django's models and handles HTTPS requests for storing and updating required information about products, orders, and events. Each model typically maps to a single (SQL) database table. A separate database system (MySQL, PostgreSQL, etc.) is also possible;
- a webpage on Django containing information about the order rows associated with the QR codes and previous events registered to them. User registration/authentication in Django's system is required upon opening the webpage. From this webpage users/operators can also register new events for the order row. These new events also appear in the monitoring pages, allowing the customer to see every event registered to the whole order, as well as the current status of each separate order row;
- a smartphone an operator uses to retrieve information and to register events. The Django server provides a simple camera view of the webpage that automatically parses any QR code detected in the picture. To make it easy, JavaScript and Instascan (<https://github.com/schmich/instascan>) with a free MIT license were used. All the communication occurs securely via an HTTPS browser;
- a Huawei E3372 laptop with a dongle internet connection and a virtual workstation in the university's systems.

The technical specifications presented above show that the system software architecture was built from available and free solutions. The QR code-based system does not require any infrastructure solutions in the factory and supply chain but only a basic smartphone connected to the internet. This is simpler and cheaper than an RFID-based system as presented in the previous section.

A demo video (3:14 min) of the system was recorded using a smartphone. The video presents a description of the system (1.1.-1.3.) and its operation (2.1.-2.11) with the following steps and subtitles:

QR code-based order monitoring system

- 1.1. mobile device to register events at shop floor level;
- 1.2. QR stickers attached to orders;
- 1.3. cloud-based system to monitor order status in real time;
- 2.1. order goes to production at workstation (WS) #1;
- 2.2. once the job is completed at WS#1, the operator scans the QR code, checks the order information, registers an event of 20% progression of work, selects the location, and submits the event;
- 2.3. order status is updated in real time in the system;
- 2.4. order continues to WS#4;
- ...
- 2.7. another order goes to production at WS#3;
- ...
- 2.10. order goes to the shipping area and is 100% complete;
- 2.11. dispatcher scans the QR code and registers an event indicating that the order is ready for shipment.

3.2. Virtual workshop and feasibility study

A one-hour virtual workshop in Microsoft Teams was arranged to discuss and evaluate the feasibility of the QR code-based order monitoring system. Representatives from four large companies participated in the workshop. The companies manufacture different products in Finland: forest machinery, pumps, wiring accessories, and marine equipment. The participants first watched the demo video to get ideas about the system and to present their views on the feasibility (pros and cons, etc.) of the system in their subcontractor network. This was followed by general discussion on further research ideas and needs.

After the workshop, the participants evaluated the technological and operational feasibility of the proposed system if it were extended and applied as a material flow monitoring system in their company and subcontractor network. Five participants answered the nine statements (on a Likert scale of 1-5) with the results presented in Appendix A. According to the results, the companies see that:

- the QR technology and solution are practical (3.6) and mature enough to be easily applied (3.6);
- the level of expertise required to realize the technical system is too high for the companies (2.6);
- the links to the ERP system are challenging to construct (1.8);
- the system enables accurate and real-time reporting (3.6), quick response (3.2), and other benefits (3.4);
- adapting the system to the operations of a subcontractor network is challenging (2.4);
- there are alternative monitoring solutions to be found on the market (3.4).

The companies were interested in following the development of the QR code system on the market. It was also found that there are possibilities of integrating the QR code monitoring system into the MES.

4. Managerial implications

The prototype system that was developed has several applications in managing supply chains. Implementation of the system in full scale to monitor MTO and ETO parts and subassemblies would provide the following benefits:

- ensures the availability of parts in final assembly well in advance;
- reduces the overall uncertainty related to materials delivery;
- reduces the need for prior verifications through direct contact by telephone and email;
- reduces the need for inbound storage;
- improves the synchronization between the principal company's and subcontractor's manufacturing operations;
- reduces the administrative burden on the subcontractor, thanks to reduced inquiries from customers;
- enables more accurate tracing of parts and related processes.

5. Conclusions

This paper proposed a QR code-based order monitoring system in a subcontractor manufacturer network. The system enables principal companies to monitor their SC upstream remotely and in real time. The supplier's production operators access the order/product information by scanning specific QR codes using a mobile device. After the completion of each step, the operators register related events using the device. The order status information is stored to a cloud database.

A prototype version of the system was built and demonstrated to representatives from manufacturing companies in a virtual workshop. The feasibility of the system was studied through discussion and a questionnaire. The QR code-based solution was found to be practical and potentially holds out the promise of better management of SCs. The companies, however, recognize that its integration into the existing ERP systems, as well as into subcontractors' systems, is challenging.

The present study is one of the few attempts to propose a system and evaluate QR code-based traceability in a manufacturing SC. A further study could expand and test the system in case companies. An extensive analysis on current SC monitoring practices and needs in the manufacturing sector should also be conducted. Company needs, along with digitalization, will surely lead development towards new and more useful applications and easier implementation.

CRedit author statement

Jaakko Peltokorpi: Formal analysis, Investigation, Writing - Original Draft, Visualization. Lauri Isojärvi: Investigation, Methodology, Software, Data Curation. Kai Häkkinen: Conceptualization, Writing - Original Draft, Methodology, Visualization, Project Administration. Esko Niemi: Writing - Reviewing and Editing, Supervision, Funding Acquisition.

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Appendix A. Feasibility study results

