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Links between kit quality and kit preparation design

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ABSTRACT
Kitting is a materials-feeding principle commonly used with mixed-model assembly, but literature is lacking with respect to how kit quality can be supported. The purpose of this paper is to create an understanding of the links between kit preparation design aspects and kit preparation error types, that can be useful to support kit quality. The paper draws on empirical data from a multiple case study in the automotive industry to study how typical kit errors are linked to eight kit preparation design aspects: location, work organisation, storage policy, batching policy, storage packaging, kit carrier and container, picking information system, and error communication. The findings suggest several opportunities related to kit preparation design aspects for preventing kit errors and facilitating kit error corrections. The paper extends earlier knowledge and can support kit quality of industrial kit preparation.

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Materials handling; warehouse design; kitting; order picking; mixed-model assembly

Introduction

Mixed-model assembly usually involves a multitude of components, and timely supply of the correct materials in the assembly process is essential (Kovács 2020; Saez-Mas et al. 2020; Kilic and Durmusoglu 2015). Here, the materials supply principle of kitting – in which assembly processes are supplied with kits of pre-sorted components for each assembly object (Bozer and McGinnis 1992) – is increasingly used and has been associated with many benefits, especially when there are many component variants (Sternatz 2015; Limère, Van Landeghem, and Goetschalckx 2015; Caputo and Pelagagge 2011). Some reports maintain that using kitting can improve the quality of the assembly process by making it easier for the assembler to find the right components (Medbo 2003). However, other reports suggest that kitting can compromise the quality of the assembly process, as kit errors can occur during kit preparation (Caputo, Pelagagge, and Salini 2017a; Caputo, Pelagagge, and Salini 2017b; Hanson and Brolin 2013). Kit errors can lead to costly disruptions if they reach the assembly process, for example requiring the assembly process to stop unless the right components are supplied in time, or that the wrong components are assembled onto end products (Boysen et al. 2015). Quality cost is considered by Caputo, Pelagagge, and Salini (2020) when modelling the cost of various manual and automation-assisted kitting systems, concluding that kitting quality is relevant when comparing kitting with alternative parts feeding policies. That is, to apply kitting effectively in industry, reducing the number of kit errors and quality-related costs associated with kit preparation is critical. While quality plays an important role in modern logistics systems, as found by Winkelhaus and Grosse (2020) on the theme of Logistics 4.0, there is still little consensus in the industry about how kit quality can be supported when kitting is used.

Given the importance of kit quality, literature that explains how kit preparation design can support kit quality is rare. Previous research has established what types of kit errors that can arise with kit preparation, including wrong components, missing components, damaged components, wrong quantity of components, and wrongly positioned components within kits (Caputo, Pelagagge, and Salini 2017a, 2017b). Several links between kit quality and kit preparation design aspects have been suggested by previous research, for example with respect to how picking information is conveyed (e.g. Hanson, Falkenström, and Miettinen 2017), location of the kit preparation workspace (Hanson, Johansson, and Medbo 2011), and how the kit containers are designed (Hanson and Brolin 2013; Brynzér and Johansson 1995). However, the available literature is far from exhaustive and rarely addresses how kit errors are linked to kit preparation design. More research about the aspects that affect kit

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quality has been recommended (Hua and Johnson 2010), and more knowledge on the topic is needed in industry. The purpose of this paper is to create an understanding of the links between kit preparation design aspects and kit error types.

This purpose is addressed by means of a case research approach, which allows for the links between design aspects and kit errors of kit preparation to be identified, as well as for rich descriptions to be developed for how the links are made up. Such knowledge is useful in a variety of industrial contexts as a means for improving kit quality associated with kitting applications.

The paper is organised as follows: first previous research related to kit quality, kit errors, and kit preparation design aspects is reviewed, ending up with a theoretical framework to support the case research. Thereafter, the method is described, followed by a description of the cases – showing how kit quality is linked to design in each case – and a case analysis that identifies how aspects of kit preparation design link to kit error types. Finally, the findings are discussed and the conclusions are presented.

Theoretical framework

This section is divided into two parts. In the first part, previous research related to kit quality and kit preparation is reviewed, and shortcomings in the research literature around the paper's purpose are highlighted. In the second part, a framework for analysing the cases is derived from the reviewed literature, shown in Tables 1–3. Previous research dealing with kit quality and kit preparation is scarce. Therefore, the framework is partly derived from literature about quality in the similar area of warehouse order picking, where the topic has received more attention.

Table 1. Kit error types prominent in the research literature.

Kit error type	Description	Highlighted by
Wrong component	A different component than required is included in the kit.	Caputo, Pelagagge, and Salini (2017a), Caputo, Pelagagge, and Salini (2017b), Brynzér and Johansson (1995)
Missing component	A component is missing from the kit.	Caputo, Pelagagge, and Salini (2017a), Caputo, Pelagagge, and Salini (2017b)
Defective component	A component with damages or manufacturing errors is included in the kit.	Caputo, Pelagagge, and Salini (2017a), Caputo, Pelagagge, and Salini (2017b)
Wrong quantity	Too many or too few components of a part number included in the kit.	Caputo, Pelagagge, and Salini (2017a), Caputo, Pelagagge, and Salini (2017b), Brynzér and Johansson (1995)
Wrong position	A component is positioned incorrectly within the kit.	Caputo, Pelagagge, and Salini (2017a), Caputo, Pelagagge, and Salini (2017b)

Table 2. Relevant aspects of kit preparation design with respect to kit quality, according to the literature.

Design aspect	Description	Highlighted by
Work organisation	The tasks included in the job of the operator who performs the kit preparation.	Grosse et al. (2015), Hanson and Brolin (2013), Brynzér and Johansson (1995)
Storage policy	The organisation of the components at the kit preparation workspace.	Grosse et al. (2015), Brynzér and Johansson (1996)
Batching policy	The number of orders handled during the same kit preparation work cycle.	Hanson, Medbo, and Johansson (2015), Brynzér and Johansson (1995)
Kit carrier and container	The design of the kit carrier and container.	Hanson and Brolin (2013), Brynzér and Johansson (1995)
Storage packaging	The type of packaging used in the storage.	Brynzér and Johansson (1995)
Picking information system	The type of system applied for conveying picking information and carrying out confirmations.	Fager (2018), Hanson, Falkenström, and Miettinen (2017), Battini et al. (2015), Marchet, Melacini, and Perotti (2015), Min (2006), Brynzér and Johansson (1995)
Location	The location of the kit preparation workspace within the production system.	Hanson, Johansson, and Medbo (2011), Brynzér and Johansson (1995)
Error communication	The approach used for the identification and reporting of kit errors.	Caputo, Pelagagge, and Salini (2017a), Caputo, Pelagagge, and Salini (2017b), Hanson, Johansson, and Medbo (2011)

Table 3. The two types of links between kit errors and kit preparation design aspects considered.

Link type	Description	Highlighted by
Kit error prevention	Links between design aspects and kit errors that help prevent kit errors from occurring during kit preparation	Fager (2018), Hanson, Falkenström, and Miettinen (2017), Battini et al. (2015), Grosse et al. (2015), Marchet, Melacini, and Perotti (2015), Hanson and Brolin (2013), Min (2006), Brynzér and Johansson (1995)
Kit error correction	Links between design aspects and kit errors that help correct kit errors that reach assembly	Caputo, Pelagagge, and Salini (2017a), Caputo, Pelagagge, and Salini (2017b), Hanson, Johansson, and Medbo (2011), Brynzér and Johansson (1995)

Previous research dealing with quality in kitting and warehouse order picking

In two recent studies, Caputo, Pelagagge, and Salini (2017a) and Caputo, Pelagagge, and Salini (2017b) developed comprehensive models for estimating the costs of kit errors in kit preparation. They defined five error types: missing component, wrong component, damaged component, wrong number of components, and wrong component position, and developed event trees for estimating quality-related costs based on how severe the error types were for the assembly process. Caputo, Pelagagge, and Salini (2017c) further linked the error types to part-specific features and human task perception. While these models allow the quality-related costs of kit preparation to be estimated when selecting among supply principles, they do not discuss what kit preparation design to apply for supporting kit quality.

When comparing the economic impact of different types of paperless technologies in warehouse order picking, Battini et al. (2015) showed how various error types can occur when pickers interact with picking information systems. The errors were modelled in two main categories: detectable and propagating errors. Detectable errors could be detected during the picking work cycle, for example when the confirmation was wrong. Propagating errors could only be detected by the recipient of the items, for example when the confirmation was correct, but the items or quantity were wrong.

On the basis of comprehensive case research in the automotive industry, Brynzér and Johansson (1995) proposed several approaches to prevent kit errors in kit preparation, for example by having assemblers perform kit preparation and make use of their assembly knowledge to support picking accuracy, or by reducing disturbances during the work cycle to decrease the risk for mistakes. A main conclusion was the importance of how the picking information system is designed. Brynzér and Johansson (1996) developed a method for storage assignment with respect to the picker's perspective. The benefit of this method was improved efficiency and reduced errors in the picking work cycle.

When studying the impact of the location of kit preparation on in-plant materials supply performance, Hanson, Johansson, and Medbo (2011) did not identify any direct links to how the location affected the number of kit errors. However, they found that location is critical for the response time of supplying components to correct kit errors. In a case study of the relative effects of materials supply by means of kitting, Hanson and Brolin (2013) highlighted the kit's design as an important aspect for kit quality and emphasised that the picker's knowledge of the assembly process could be beneficial.

When studying the efficiency impact of batch size in kit preparation by means of two experiments, Hanson, Medbo, and Johansson (2015) emphasised that while batching appears beneficial for efficiency, it may be more difficult to ensure kit quality when a batching approach is applied. In an industrially relevant experiment in kit preparation, Hanson, Falkenström, and Miettinen (2017) compared the number of kit preparation errors when applying a paper pick list or a head-up display (HUD) with mixed-reality for conveying picking information. They found that the HUD-system resulted in markedly fewer errors, owing to a more effective conveyance of picking information by the HUD-system. In a kit preparation experiment, Fager (2018) compared the number of errors associated with the four confirmation methods, barcode ring-scanning, button presses, voice commands, and RFID-scans with double wristbands, and provided insights into how errors can arise in kit preparation when confirmation methods are applied.

Utilising a multiple case study of warehouse order picking, Marchet, Melacini, and Perotti (2015) found that an anticipated reduction of picking errors was a common motive for companies to apply automation or picking information systems such as pick-by-light. Similarly, in a study on warehouse management systems, Min (2006) noted that pick-by-voice systems that are integrated with the warehouse management system offer great potential in terms of reducing picking errors.

In warehouse order picking, Guo et al. (2015) carried out an experiment comparing the number of picking errors associated with various types of picking information systems. They found that systems in which the picking information is conveyed by a HUD or a cart-mounted display resulted in markedly fewer picking errors than did pick-by-light or a paper pick list.

In a literature review of human factors in warehouse order picking, Grosse et al. (2015) highlighted four design aspects with respect to quality: storage assignment, batching policy, layout, and work organisation. Based on a comprehensive case research study of order picking in warehouses, Glock et al. (2017) identified how deviations from the prescribed work standard – so-called maverick picking – can affect picking quality. They found that quality comes at risk with maverick picking, but also that pickers can find more effective ways to carry out the work in poorly designed systems.

Framework for analysing links between kit errors and kit preparation design

From the reviewed literature, it can be seen that previous research has described the types of kit errors that can arise in kitting systems, and how their costs can be estimated if probabilities of the errors' occurrences are known (e.g. Caputo, Pelagagge, and Salini 2017a). Moreover, previous research has estimated the economic impact of various types of errors that can occur in order picking when a picking information system is used, accounting for that errors either can be prevented during picking work cycles, or corrected when they reach the recipient (e.g. Battini et al. 2015). However, research regarding how to support kit quality of kit preparation remains scarce, and apart from a few contributions (e.g. Brynzér and Johansson 1995), there is an evident lack of guidance.

It is useful to here specify the terms kit quality and kit errors in light of the reviewed literature. Based on the reviewed publications, a taxonomy of kit preparation errors to be used in the current study has been created, shown in Table 1. Kit quality, then, is viewed as absence of errors of the types in Table 1.

As already highlighted, previous research has pointed out several aspects related to the design of processes for kit preparation that can affect kit quality. While previous studies on the topic have shown that there are aspects beyond design that play an important role for kit quality, e.g. aspects related to component characteristics and how humans perceive their task (see e.g. Caputo, Pelagagge, and Salini 2017c), the focus of this paper is on how design aspects of kit preparation link to kit error types. Those design aspects that have been put forth in previous studies serve as an appropriate starting point with respect to the paper's purpose, and are shown in Table 2.

Moreover, the literature indicates that there seems to be two types of links between kit errors and kit preparation design aspects, i.e. kit error prevention and kit error correction, both by which kit quality could be supported, see Table 3.

The first link type is *kit error prevention*, meaning to prevent errors from occurring during kit preparation, for example as presented by Brynzér and Johansson (1995). This would amount to preventing the error types defined by Battini et al. (2015), Caputo, Pelagagge, and Salini (2017a) and Caputo, Pelagagge, and Salini (2017b) from occurring in the first place.

The second link type is *kit error correction*, meaning the correction of kit errors that reach assembly processes. An example is to improve response time for supplying the right component by using a location closer to the assembly process, as identified by Hanson, Johansson, and Medbo (2011). Such links can help address the propagating errors in the model by Battini et al. (2015), and the severity of various error types in Caputo, Pelagagge, and Salini (2017a) and Caputo, Pelagagge, and Salini (2017b).

In line with the purpose of the paper, i.e. to create an understanding of the links between kit preparation design aspects and kit error types, the two types of links for supporting kit quality shown in Table 3 are applied as a guide in the case analysis to categorise any links between kit errors and kit preparation design aspects, as outlined in Tables 1 and 2, respectively.

While this approach is based on the previously available knowledge, it brings together this knowledge in order to study the topic from a case research standpoint. The focus is on identifying approaches for kit error prevention and kit error correction that are linked to kit preparation design. This is new in literature.

Method

The paper adopts a case research approach to study the links between kit preparation design aspects and kit error types. A case research approach was chosen because it can make use of both qualitative and quantitative data (Ketokivi and Choi 2014; Voss, Tsikriktsis, and Frohlich 2002), and can uncover both broad and in-depth findings. This would not be achievable with purely statistical approaches, since these would rely on the links to already be known.

Case selection

A case was viewed as a process for kit preparation, including its interfaces towards the materials supply and assembly systems. The case selection was carried out in two stages. The first stage involved studying case candidates at three automotive OEMs, here denoted company 1, 2 and 3. These studies involved mapping typical settings of design aspects among the case candidates.

In the second stage, three cases were selected amongst the case candidates, here denoted as cases A, B and C. Cases A and B were both from company 1 – case A from their logistics division and case B from their production division. Case C was from the engine production plant of company 3. No cases were selected from company 2 because the case candidates there generally had made few changes of their kit preparation design with respect to supporting kit quality. However, it was ensured when cases A, B and C were selected that the kit preparation design aspects used at company 2 largely matched the design aspects of the three selected cases. The design aspects of cases A, B and C are shown in Table 4.

Cases A, B and C were chosen in part because they individually had made significant changes over time for reasons of improving kit quality (true for all three cases), and in part because of their fit with respect to replication logic (Voss, Tsikriktsis, and Frohlich 2002) amongst

Table 4. Design aspects of the cases.

Design aspects	Case A	Case B	Case C
Location	∼ 150 m away from assembly (in warehouse)	∼ 20 m away from assembly	∼ 10 m away from assembly
Work organisation	Only picking	Picking and assembly on rotation	Picking and assembly within each cycle
Storage policy	Class-based (demand); Similar components separated	Class-based (demand); Similar components separated	Dedicated
Batching policy	48 kit batch	10 kit batch	1 kit batch
Kit carrier and container	Four sides with a grid of six by four compartments; one component per compartment, two compartments per kit	Two by five grid of 200 × 600 mm boxes; 10–12 components per kit, in the same compartment in the box (kit)	Trolley with fitted slots; one component type per slot; 30–34 components per kit; one kit per trolley
Storage packaging	EUR 1200 mm pallets with two frames; 800 × 600 mm boxes; Plastic wrapping around components	EUR 1200 mm pallets with four frames; 200 × 300 mm and 300 × 400 mm boxes	EUR 1200 mm pallets with four frames with internal cardboard spacers; 300 × 400 mm boxes
Picking information system	Pick-by-voice and barcode ring scanner	Pick- and-place-by-light with motion sensors (shelf and trolley)	Pick-by-light with buttons (shelf)
Error communication	Records kept	Records kept (unreliable)	No records

important settings of kit preparation design aspects. Together, the design aspects of cases A, B and C largely matched the design aspects of the case candidates, as well as covered important design aspects brought up in the research literature (see Table 2).

To exemplify the applied replication logic, with respect to location, it was ensured that the cases covered different distances from assembly (case 1 was far away while cases 2 and 3 were close by). With respect to picking information system, pick-by-voice and pick-by-light are typical in industry and were the most used types among the case candidates. These system types have also been prominent in the research literature (e.g. Fager et al. 2019; Battini et al. 2015; Guo et al. 2015).

Paper pick lists constitute a traditional approach to conveying picking information and are still common in kit preparation. Paper pick lists were not in current use in any of the selected cases, but in all three cases, they had been used prior to the introduction of the current systems, which made it possible to consider the use of paper pick lists indirectly, as a point of reference.

Data collection and analysis

With case research, multiple sources of evidence are recommended (Ketokivi and Choi 2014; Voss, Tsikriktsis, and Frohlich 2002). With respect to the paper's purpose, it is critical to identify what links between kit errors and design aspects of kit preparation exist, and how these links are made up. This paper relies on interviews, direct observation, and review of secondary sources.

Interviews were performed with managers, logistics team leaders, and pickers for each of the cases. For each case, a one to two-hour semi-structured interview was performed with one to three managers responsible for the kit preparation. Additionally, informal interviews were performed with pickers, logistics team leaders and technicians. All interviews were conducted on-site and the interviews with the managers were organised using an interview template, developed based on the theoretical framework. The questions were organised in three sections that concerned (1) what types of kit errors usually occurred; (2) reasons for why the kit error types occurred and what had been done design-wise to prevent them; and (3) how kit errors were identified and corrected. All interviews were organised as semi-structured, which allowed for follow-up questions and more in-depth discussion to enrich the findings (as suggested by Voss, Tsikriktsis, and Frohlich 2002).

Direct observation – on-site and from video-recordings – was performed for all three cases during operation. While it was not possible to observe any kit errors as they occurred, the observation allowed for an improved understanding of how kit errors could occur in the cases, as had been described during the interviews. A review of secondary documentation, in form of records of kit errors (case A), layout schematics (all cases), and information about the components (all cases), was performed as a complement to the interviews and observations.

For each case, an in-depth analysis of the links between kit preparation design aspects and kit error types was carried out. Each case was first analysed individually by how kit quality was affected by the design aspects of the cases. Thereafter, the findings were compared between the cases to identify how the design aspects can support kit quality by either preventing kit errors from occurring, or by facilitating kit error corrections. During the analysis, clarifications and additional follow-up questions were asked to the interviewees by telephone. The findings from each case were later presented to the interviewees for validation.

Case descriptions

The three cases are from the automotive industry; each making up a process for preparation of kits for mixed-model assembly. For each case, the designs are described, and findings related to kit quality are presented. The findings are organised based on the two link types in Table 3: kit error prevention and correction. In the next section, the case findings are analysed with respect to the design aspects in Table 2, in terms of how the design aspects relate to the kit error types in Table 1.

Case A

Design of case A

Case A concerns sequenced deliveries of rear-view mirror kits for automobile assembly. The kit preparation workspace was located in a warehouse, and the kits were delivered to assembly by a tugger-train. The layout (Figure 1) was a picking aisle with storage racks on both sides. Boxes were presented in flow racks, and pallets were presented on shelves. Two kit carriers were positioned at the kit area, each carrying 48 kits. The kit carrier could be rotated to display any side, each holding 12 kits, to the picker. A kit consisted of a rear-view mirror and a mirror cap. All rear-view mirrors were wrapped in plastic, due to being sensitive for scratches, and the plastic wrapping was discarded in trash bins during the work cycle. Pick-by-voice was applied as picking information system, together with a barcode ring scanner with which the picker scanned each rear-view mirror and its location in the kit carrier.

Findings related to kit error prevention from case A

Wrong component errors, for example a mirror cap of the wrong colour, could occur in a variety of situations. Typically, it could occur if a pick was made from the wrong location while the correct check-digit was reported in the pick-by-voice system. It could also occur if two components were switched between kits, or if the batch of kits presented on one of the four sides of the kit carrier was completed in the wrong order. The barcode scans of the components and the kit compartments helped prevent all these situations.

The error type could occur as materials were sometimes replenished to the wrong location. Here, a replenishment control to verify that the replenishments were correct, performed by the picker using the pick-by-voice system, helped prevent that these situations led to kit errors.

Another situation was when there were mixed contents in the storage containers. The contents could become mixed when a wrongly picked component was incorrectly restocked by the picker. This was reportedly more frequent when similar-looking components were stored next to each other, and the storage policy was, therefore, to store similar-looking components separately.

Discarding of plastic wrapping and handling of empty containers was a disturbance that could result in the picker forgetting in which compartment to place the next component, or what component to pick next, leading to wrong component errors. To reduce these disturbances, packaging discarding points had been positioned with respect to the picker's movement pattern, including trash bins for discarding plastic wrapping positioned near the kit carriers, and output lanes for empty containers at each shelf, see Figure 1. The pick-by-voice system provided support in some situations, as the picker could have the last instruction repeated, but there was no way to redo an order line which had already been completed.

A paper pick list was used before the pick-by-voice system was introduced. An issue with the list was that the picker learned patterns of what components were usually picked. At new product introductions, many kit errors occurred as the picker followed learned patterns. With the pick-by-voice system, the picker reportedly relied less on the learned patterns. However, the

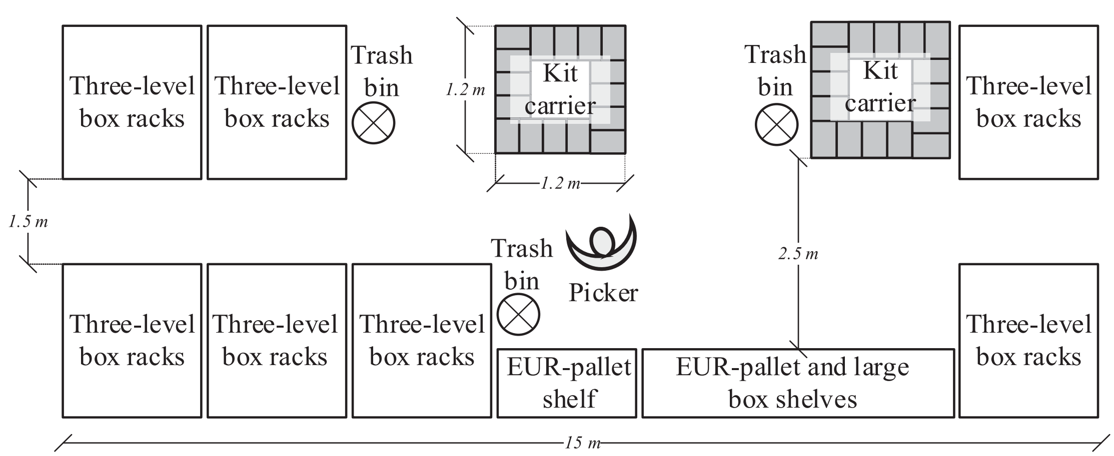

Figure 1. Layout of case A, preparation of kits with rear-view mirrors and caps to an automobile assembly process.

company found that if pickers learned which check-digit belonged to which component, the right check-digit could be reported without the right component being picked. Therefore, the company used three check-digits for each storage location and alternated among them between picking rounds. The check-digits were also updated every second week.

Missing component errors were rare, as it was obvious if a compartment was empty, but still occurred occasionally. One such situation was in association with materials shortages, for instance when the picker worked ahead of the schedule or when a replenishment was delayed. The pick-by-voice system was a good support in this respect, as it reminded the picker to supplement any backlogged components at the end of the picking tour. However, sometimes the kit carrier was mistakenly picked up by the tugger-train and delivered to assembly before the supplementation was done.

Defective component errors were rare, but occasionally occurred. There were several safety precautions used to prevent scratches on either the mirrors or the mirror caps. All components were packaged in plastic wrapping inside the storage containers. Furthermore, the pickers wore cotton gloves to prevent from scratches and finger prints, and the compartments in the kit carriers were coated with soft material. Additionally, the pickers inspected each component before it was placed in a kit and discarded any component that had been accidentally dropped.

Wrong quantity errors or *wrong position errors* had not been encountered, as each compartment in the kit carrier only had room for a single component and there was no positioning requirement inside each compartment. However, a quantity check was still used with the pick-by-voice system, where the picker had to vocalise the picked quantity to receive the next instruction.

Findings related to kit error correction from case A

When a kit error was detected at the assembly process, the right component was supplied by express delivery from the warehouse, called for by the assembly team leader. Owing to the distance, the delivery usually took a couple of minutes. To avoid stopping the assembly process, the assembler, when possible, cannibalised from another kit.

The assembly team leader filed a report when a kit error was detected. The reports were compiled into kit error records for the whole division of about 20 processes for kit preparation. The division's average reported error rate was 22 errors per million components picked. The reports were used by the kit preparation managers to identify the errors' causes and remedy these, in order to prevent further kit errors of the same kind.

Case B

Design of case B

Case B prepared kits with engine coating components for a car assembly line. The kit preparation workspace was located close to the assembly process, to which the picker manually transported the kit carrier. The picker rotated between kit preparation and assembly between shifts. The layout, shown in Figure 2, consisted of a straight and open-ended picking aisle with storage on both sides – flow racks with boxes and pallets on carts. Kits were prepared in batches of ten, and each kit contained ten to twelve components. The 10 kit containers on the kit carrier was plastic boxes ($600 \times 200 \times 200$ mm), and the components had no specific positioning within the kit. A pick-by-light system guided the picker, indicating one picking location at a time and all of the kit containers that should receive that component. Motion sensors were applied on the shelves (positioned above each storage location) to confirm picks and on the kit carrier to confirm placements.

Findings related to kit error prevention from case B

Wrong component errors occurred due to mixed contents in the storage container. This could be due to the materials supply, but usually occurred when too many components were picked, and the extras were restocked at wrong location. In this respect, similar-looking components were seen to be more of a risk, for example right and left-sided battery covers, as were small-sized components. A policy of separating similar-looking components at the kit preparation workspace was therefore used, which was thought to be effective. However, the possibility of separating similar-looking components was limited, since the components used first in the assembly process needed presentation at the end of the aisle, and vice versa, for the components to be accessible in the right order in the assembly process.

Another typical cause of a wrong component error was that components got misplaced between kits, attributed to the relatively large batch size (ten kits). The place-by-light system was found to reduce the risk of misplacing. An issue with the setup was, however, that the picker could hold off with performing the confirmations until after all the placements had been made, to save time.

New product introductions were associated with wrong component errors, as there was a tendency to overlook the new components. Introducing pick-by-light, instead of the previously used paper pick list, made it less of an issue, as it allowed the picker to follow the instructions and pay less attention to what components to pick.

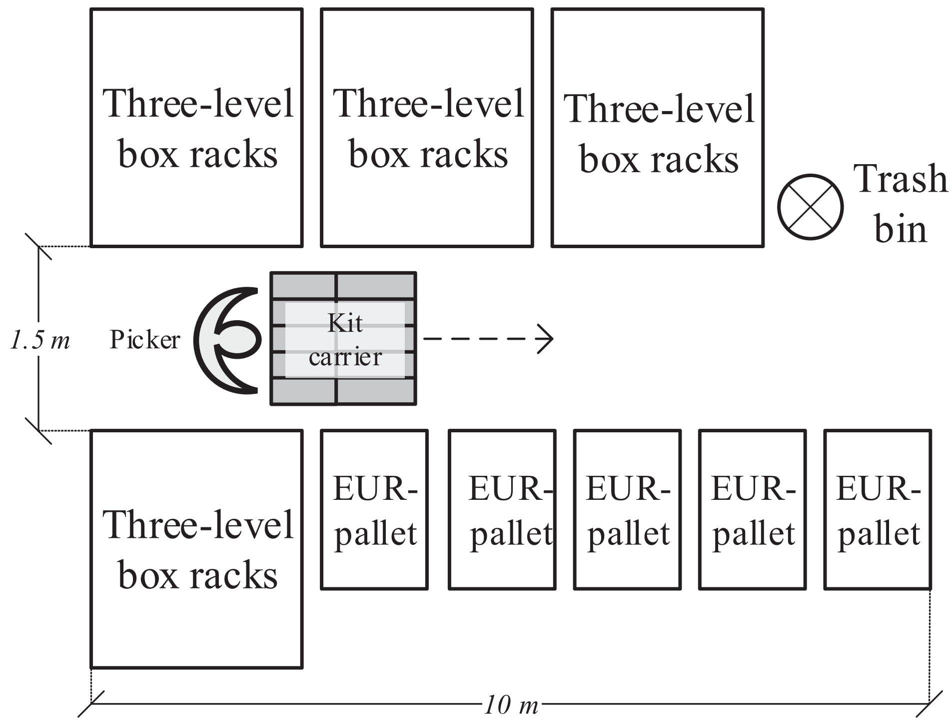

Figure 2. The layout of case B, preparation of kits with engine coating components for a car door assembly line.

Missing component errors were typically associated with material shortages. Shortages usually affected several kits in the batch and led to multiple kit errors if the kits were supplied to assembly before the components were supplemented. The picker could press a button to signal that a shortage had occurred and continue the work cycle. A message on the carrier-monitor then reminded the picker to supplement the missing components after the work cycle.

Defective component errors were seen as an issue for some of the components. Some of the components, sensors for example, were sensitive to dust. Here, it was key to keep the kit preparation workspace clean from dust, and the picker had to inspect that the sensors had not become defective due to dust.

Wrong quantity errors in the kits could occur when the picker assumed what quantity to pick from previous experience of working in the process. As a countermeasure, signs were installed on the shelves that displayed the quantity to pick, for components that hade the same number in all kits. For components that varied between kits, the picker relied on the pick-by-light system displays.

Wrong position errors were not seen as an issue, the components required no specific positioning.

The picker's knowledge of the assembly process, gained from performing assembly tasks on rotation, reportedly helped the picker identify correct and non-defective components. It was emphasised that the picker could become distracted during the picking tour, for example due to chatting with a colleague or discarding empty boxes or inner packaging, and thereby lose track of the next activity. This was reportedly a cause of all the kit error types reported above. As there was no way to redo an already-confirmed activity with the pick-by-light system, the picker had to use a paper pick list to retrace any missed activities. The paper pick list was also used when the pick-by-light system was out of order, typically resulting in a rise of wrong component errors.

Findings related to kit error correction from case B

When a kit error was detected at the assembly process, the assembler was supposed to call for an express delivery of the right component. However, usually the kit error was resolved by the team assembly leader, who went to the nearby kit preparation workspace to collect the right components.

Records of kit errors were kept in case B, but the managers stated that the records were unreliable, since the kit errors usually were not reported when the assembly team leader made the correction. It was emphasised that having the team leader visit the kit preparation workspace was problematic since there was a risk of disturbing the picker during the work cycle. However, forbidding this approach was questionable since the kit preparation workspace was located close to the assembly process, and the consequences of stopping the assembly process were expensive.

Case C

Design of case C

Case C prepared kits with components for coolant pumps for a heavy-duty vehicle engine assembly process. The kit preparation workspace was located alongside the assembly process. The layout of case C, shown in Figure 3, consisted of an open-ended picking aisle with two sections of pallets stored on the floor, and flow racks with boxes of varying sizes (see Table 4). The picker pushed the kit carrier through the aisle and completed a single kit containing around 30 components. The kit container had fitted slots in which only the correct component type fitted. After the picking cycle, the picker manually pushed the kit carrier to the assembly process and assembled the components onto the engine. A pick-by-light system with button-press confirmations was applied.

Findings related to kit error prevention from case C

Wrong component errors were a typical kit error type. For example, two variants of the same component type, that both fit in the same slot in the kit container, could be confused with each other. A typical situation was when the picker fell behind in the work cycle, for example when a lot of packaging handling was carried out during the same work cycle. Then, the light-indicators for subsequent picks could be turned off to save time, which was possible since all picking locations were indicated from the start of the work cycle.

Mixed content in the storage containers was highlighted as another cause of wrong component errors, which could stem from the materials supply, but usually occurred when wrongly picked components were restocked in the wrong place. Owing to the fitted slots of the storage container, mixed content was only an issue for variants of the same component type, explaining why a storage policy of separating variants of the same component type was applied.

The picker was able to see the end product at the assembly process, which together with the picker's knowledge of the assembly process – gained from carrying out the assembly work – was reportedly beneficial for preventing wrong component errors. The reasoning was that this made the picker better at judging that only the right and undamaged components were kitted.

Missing component errors in the kits were rare, as it was obvious if a slot was empty, but had occurred in association with material shortages when the missing component had not been replenished in time before the assembly cycle began.

Defective component errors were not seen as issue since most of the components were unsensitive. However, the kit preparation workspace was regularly cleaned to keep the components free from dust, as some of the coolant pump components could be sensitive to dust exposure. Furthermore, owing to that the pickers also performed assembly, their knowledge of component quality was

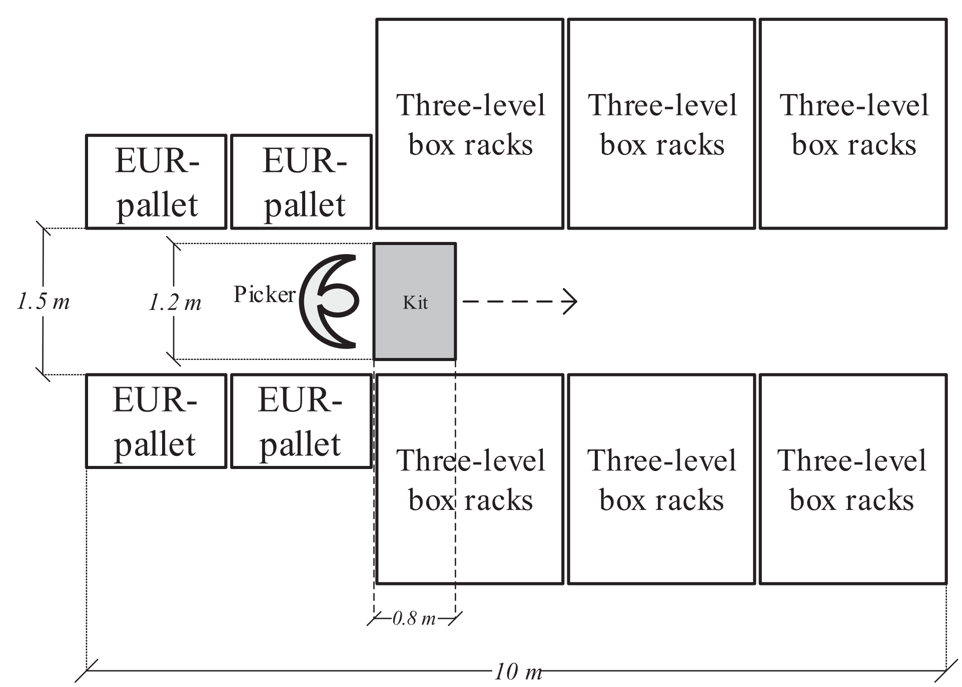

Figure 3. Layout of case C, preparation of kits with components for coolant pumps for a heavy-duty vehicle engine assembly process.

high, and they could easily detect deficiencies that, for example, stemmed from the manufacturing process.

Wrong quantity errors were reportedly effectively prevented by the fitted slots in the kit container, as only a single component type fit per slot.

Wrong position errors were prevented by the use of fitted slots, since there only was one slot available for each component type.

Distractions from, for example, packaging handling or informal conversations with a colleague, were emphasised as problematic since the picker could accidentally miss an activity. This had been associated with all kit error types reported above. To supplement missed components, the picker used a paper pick list, since already-confirmed activities could not be repeated in the pick-by-light system. The picker also used the paper pick list when the pick-by-light system malfunctioned, but using the list was usually associated with spikes in the number of kit errors. These spikes were attributed to the high component variety at the preparation workspace, which did not matter when the pick-by-light system was used, as the picker then followed the light-indicators.

Findings related to kit error correction from case C

Kit errors detected at the assembly process were usually resolved by the assembler or by the assembly team leader visiting the preparation workspace to collect the needed components. This was a quick procedure since the preparation workspace was located close to the assembly process. Moreover, as the picker had a direct line of sight with the assembly process, coordination between the assembly and kit preparation was described as effective, and the needed components could be collected without any issues most of the time.

No records of kit errors were kept for case C, owing to the quick procedure for making kit error corrections. However, a tool called the 'quality assurance matrix' was used to follow up on recurring kit errors.

Identified links between design aspects and kit errors

This section presents the paper's findings. The section is organised in two subsections that each presents links between kit preparation design aspects and kit errors as identified from the cases, with respect to kit error prevention, and kit error correction. Within each subsection, the findings are organised after the design aspects in Table 2. A summary of the findings is shown in Table 5, presenting the identified links between kit error types and kit preparation design aspects, highlighting the type of link and by what cases the link was identified.

Kit error prevention links

Work organisation

From the cases, there seems to be a preventive effect on the kit error types wrong component and defective component from the picker knowing the assembly process and its requirements. This was the case in case B, where the picker performed kit preparation and assembly on rotation, and case C, where the picker first prepared the kit and then carried out assembly. However, new product introductions were as problematic in cases B and C as they were in case A, where the picker only performed kit preparation, as the pickers were unfamiliar with the new products.

It seems that while a preconception of picking work, gained from performing assembly tasks, can aid the picker in judging that the correct and non-defective components are kitted, it still is important that the picking information system is used in order to prevent wrong component errors when, for example, new products are introduced. Moreover, it seems that if the assembly and kit preparation tasks are performed in the same work cycle, as in case C, it leads to a more up-to-date preconception of the components to pick, as opposed to assembly and kit preparation tasks being performed separately, as in case B.

Storage policy

As seen in all three cases, an important approach with the storage policy to prevent wrong component kit errors is to separate similar-looking components at the kit preparation workspace. This seems to reduce the risks of the picker mistaking one component variant for another, and the picker restocking a wrongly picked component at the wrong place, leading to risks of kit errors later on. As seen in case B, the possibility to separate similar-looking components may, however, be restricted by the order in which the components must be presented.

Batching policy

The processes which prepared kits in batches (cases A and B) had encountered components being placed in the wrong kit, leading to both wrong component and missing component errors. The single kit policy applied in case C did not share this risk, as there was only on kit container available during each picking tour to place components in. This is in line with previous research (see Brynzér and Johansson 1995; Hanson, Medbo, and Johansson 2015), which has pointed out that large batch sizes generally lead to more complex picking and a greater risk of errors.

Table 5. Identified links between kit preparation design aspects and kit errors, highlighting the cases by which the links were identified, and highlighting measures that can be used to help prevent or correct kit error types.

Design aspect	Measure and description	Associated kit error types: Wrong component	Missing component	Defective component	Wrong quantity	Wrong position
Work organisation (kit error prevention)	Have pickers perform both kit preparation and assembly tasks (cases B and C), as knowledge of the assembly process can benefit picking correct and non-defective components.	X		X		
Storage policy (kit error prevention)	Separate similar-looking components in the shelves, as this can help prevent confusion when picking (all cases) and restocking (all cases).	X				
Batching policy (kit error prevention)	Use a single-kit approach to avoid risks of placing components in the wrong kit container (case C compared with cases A and B).	X	X			
	Account for the risk of completing the batch backwards when batching is used (case A).					X
Kit carrier and container (kit error prevention)	Use fitted slots to simplify for the picker to see that the correct components are picked (case C).	X	X		X	X
	Use separate compartments for components to promote keeping track of the next activity (case A).		X		X	X
Storage packaging (kit error prevention)	Consider how to effectively discard the packaging, as handling or discarding of packaging can disturb the picker (all cases).	X	X	X	X	X
Picking information system (kit error prevention)	Consider what type of picking information system to use, as it can be important (all cases when compared with paper list).	X	X		X	
	Having functions that can support correct replenishments and handling of material shortages are important (case A).	X	X			
	Using confirmations of picking (all cases) and placing (cases A and B) activities, and of quantities (case A), can be effective support.	X	X		X	
	Indicate one order line or location at a time (case A), as it can be beneficial over indicating all order lines, or locations, at once (cases B and C).	X	X		X	
Location (kit error correction)	Use locations close to the assembly (cases B and D) to facilitate kit error corrections, rather than locations further away (case A).	X	X	X	X	
	Use locations close to assembly with direct line of sight between assembly and kit preparation (case C) for more effective kit error corrections.	X	X	X	X	
Error communication (kit error correction)	Ensure a working error communication, as this can help relieve the assembler from handling kit errors (case A compared with cases B and C).	X	X	X	X	X
	Use direct feedback from assembly about kit error corrections to support kit error prevention, even if kit error records are not kept (case A compared with cases B and C).	X	X	X	X	X

Kit carrier and container

It seems that using fitted slots in the kit container, as in case C, can be an effective means to avoid the kit error types wrong component, missing component, wrong quantity, and wrong position. With fitted slots, it is easy to see if all the intended components have been included in the kit. As learned from case C, missing component and wrong quantity errors were practically impossible, as it was obvious if a slot was empty or already filled. Furthermore, it was practically impossible to pick a wrong component that had a substantially different shape, as it would not fit in any of the free slots, or to place a component with the wrong position.

Similar to the fitted slots of case C, the separate compartments in the kit container used in case A seem beneficial for preventing kit errors over using a single compartment for all components in the kit, as in case B. However, as noted in case A, the sequence in which the kits in the carrier should be filled was not obvious, and it is important that the picker is properly guided as to which sequence is correct. It should be noted that for either fitted slots or compartments to prevent missing component errors, the picker must be informed if a slot or compartment should be left empty, unless all kits prepared in the process require the same amount of component variants.

Storage packaging

It was emphasised in all cases that storage packaging handling performed during the kit preparation work cycle could distract the picker and, thereby, be a cause of any of the five types of kit errors. Depending on what type of storage packaging was applied, and whether the components were protected by inner packaging, the amount of packaging handling which was necessary could vary substantially. Sensitive components that needed to be stored with inner protective plastic wrapping to avoid scratches (case A) required that the inner packaging was discarded during the picking tour. As learned from case A, where trash bins were positioned next to the kit carrier, a well-thought-out position of the trash bin can reduce the disturbance that the discarding activities create. Similarly, with a moving kit carrier, a trash bin could instead be attached to the carrier.

Picking information system

There seem to be differences with respect to kit quality from what type of picking information system is used. In the three cases, paper pick lists had either been used previously or were used as a backup when the current system malfunctioned. Drastic improvements of kit quality were reported in all three cases when the paper pick list was replaced, especially with respect to new product introductions and low runner variants. From case C it seems that the link between how information is conveyed and kit quality depends on the component variety, which, when high, contributes to a higher complexity of picking. The order in which the pick-or-place locations are indicated during the work cycle also seems important. Having the light-indicators for all the kits that should receive components light up at once, as seen in case B, or having all the picking locations in the shelves light up at once, as seen in case C, can lead to a dissociation between the confirmations and activities carried out to save time. In contrast, case A, where pick-by-voice was applied, and the next instruction could only be received once the previous activity had been confirmed, did not display these issues. Thus, it seems that indicating the locations for activities separately can support kit quality.

Confirmations were applied in all three cases as a means of supporting kit quality and were considered as effective to this end in all cases. Additional layers of confirmation, such as the barcode scan of the product and compartment in case A, or the quantity confirmation also applied in case A, appear to be effective.

Outside the work cycle, the cases showed that picking information systems that can support that materials are replenished correctly, for example pick-by-voice systems as used in case A, can aid in preventing wrong component kit errors. Furthermore, functions for handling material shortages, which were available in the pick-by-voice system in case A, and in the pick-by-light system in case B via the monitor on the kit carrier, seem beneficial for preventing missing component errors.

Kit error correction links

Location

It was clear from the cases that the location of the workspace impacted how the kit errors wrong component, missing component, and defective component, were corrected when detected at assembly processes. In cases B and C, where the workspace was located close to the assembly process, the assembler or assembly team leader could quickly collect the needed components from the kit preparation workspace. In contrast, in case A, where the kit preparation workspace was located further away, the supply of a new component typically took longer time, which could cause cannibalisation of other kits at the assembly process, creating a risk for assembly errors. Based on the case analysis, it seems that choosing to locate kit preparation workspaces close to assembly processes will facilitate kit error corrections. However, as learned from case B, the visit to the preparation workspace to collect components may disturb the picker, which can then cause new kit errors.

In case C, the location next to the assembly process enabled a direct line of sight between the picker and the assemblers at the assembly process. This was considered beneficial for making kit error corrections of the above error types, and for the pickers to receive immediate feedback from assembly if there was a kit error. The direct line of sight hence improved communication, and coordination, between the kit preparation and assembly with respect to kit error corrections.

Error communication

The cases differed considerably with respect to record keeping and communication of the kit errors that were identified. This relates directly to kit error correction, but it relates also to kit error prevention, which is supported by knowledge of the errors that have occurred.

While the engineers in cases B and C stated that kit errors were experienced regularly, records of the kit errors were either not kept (case C), or were seen as unreliable (case B). One explanation could be that the kit errors seldom became an issue, as they could be corrected within the assembly work cycle by the assembly team visiting the nearby kit preparation workspaces to collect components. In both cases, it was possible for the kit preparation processes to receive direct feedback with respect to kit quality, and solutions for removing recurring kit errors could be found in collaboration with the assembly teams. In case A, instead, where the kit preparation took place further away from assembly, express deliveries were necessary in order to correct kit errors and it was found that the reduction of these costly express deliveries constituted a clear incentive to prevent the number of kit errors. Accordingly, in case A, reliable kit error records were kept. On the other hand, the kit preparation managers had little direct contact with the assembly and solutions for preventing recurring kit errors had to be identified based on the kit error records alone. None of the cases displayed any indication that kit errors had led to end-of-line corrections, requiring product disassembly, although the managers in all three cases acknowledged this risk.

Discussion and further research

The paper's findings support many of the links between kit preparation design and kit errors that had been identified in the literature. Moreover, several new links were identified. In line with the findings by Hanson, Johansson, and Medbo (2011), the current study identified how choosing a location close to the assembly process can facilitate kit error correction. Additionally, the study identified that quality corrections can occur ad hoc, which can lead to other kit errors, highlighting a trade-off between correcting problems quickly and correcting problems without causing disruptions. The design of the kit carrier and container was found to be crucial for quality, as identified by Hanson and Brolin (2013) and Brynzér and Johansson (1995). The paper further identified that a batching policy may compromise quality, in line with the reasoning by Hanson, Medbo, and Johansson (2015) and Brynzér and Johansson (1995), and that the storage policy (Brynzér and Johansson 1996), as well as the choice of picking information system (Hanson, Falkenström, and Miettinen 2017; Battini et al. 2015; Guo et al. 2015), are important aspects to consider from a quality standpoint. In all the cases, paper pick lists had been used before the current systems were introduced. The findings from the cases confirm the existing literature (Guo et al. 2015; Hanson, Falkenström, and Miettinen 2017) in that paper pick lists are associated with a relatively high frequency of errors. At the same time, in case B, it was noted that when the pickers relied on the regular pick-by-light system, they sometimes lost track of which activities had been performed. Here, the paper pick list, which was used as a backup source of information, offered support and in fact contributed to reducing the risk of picking errors.

The paper adds to the cost estimation models of kit preparation kit errors by Caputo, Pelagagge, and Salini (2017a) and Caputo, Pelagagge, and Salini (2017b) by identifying several ways to prevent kit errors and make corrections of kit errors easier. The paper further adds to the knowledge of how the kit quality can be supported and contributes to filling a research gap pointed out by Hua and Johnson (2010).

For the practical contribution, the findings of the paper can help prevent kit errors and facilitate error correction. The results are useful both for design of new processes and for improvement of existing processes. Furthermore, many of the findings are not unique to kit preparation but can be applicable to warehouse order picking, for example the findings related to the batching policy, storage policy, storage packaging, the kit carrier and container design, and the picking information system.

Besides quality, other performance objectives of kit preparation, such as efficiency and flexibility, are important. While using fitted slots in the kit container seems beneficial from a quality standpoint, these likely suppress efficiency, as the picker must be more precise, and can reduce flexibility, as the container has to be redesigned when new products are introduced (Hanson and Brolin 2013). Similarly, using confirmations to improve quality can reduce efficiency, as time is spent on performing confirmations (Fager 2018), and may make the design less flexible if e.g. buttons and electrical wiring are used (Hanson, Falkenström, and Miettinen 2017). Therefore, a proper analysis of all requirements for the kit preparation should be carried out before a design is chosen.

The context of the cases was found influential in several respects. An aspect that was highlighted in all three cases was the materials supply to the kit preparation workspace, where a shortage of materials at the kit preparation workspace or incorrect replenishment created many issues. As also highlighted in all three cases, and in line with previous research (e.g. Grosse et al. 2015; Grosse and Glock 2013; Hanson and Brolin 2013), knowledge and experience can help the picker to decide what components should be picked and whether the components are non-defective. However, this could also be an issue concerning new product introductions and kitting of low-runner variants.

It should be acknowledged that there is an inherent difficulty with studying kit errors empirically, as they occur infrequently and, therefore, are difficult to observe in real time. Furthermore, although records of kit errors could be collected from the cases, the records were either stated to be unreliable, or did not contain enough information about the recorded kit errors for a statistical analysis to be viable. The paper works around this limitation by building its findings on experiences and data from industrial cases and people who deal with kit errors in their daily work. With respect to studying kit errors empirically, methods based on hand- and eye-gaze tracking (Bovo et al. 2020) could potentially help predict when kit errors are about to occur and may be a valuable support in future studies.

Future research could address relations between the design and kit quality of kit preparation and order picking in controlled experiments, continuing along the lines of Guo et al. (2015), Hanson, Falkenström, and Miettinen (2017), and Fager (2018). In this respect it could be interesting to consider how quality-centred applications, such as scales, object recognition, or RFID-tagging on the component level may improve quality, or to consider how kit quality interplays with user experiences associated with alternative ways of presenting picking information, such as reported by Kim, Nussbaum, and Gabbard (2019).

The findings of the paper could also be applied in quantitative modelling studies, extending the work of Caputo, Pelagagge, and Salini (2017a), Caputo, Pelagagge, and Salini (2017b) and Battini et al. (2015), preferably from a cost-benefit standpoint. Future studies should also try to capture quality-related interventions in industry to compare, and ideally quantify, the kit quality before and after an intervention is made, along the lines of Hanson and Brolin (2013).

Conclusions

Drawing on empirical data from three industrial cases of kit preparation for mixed-model assembly, this paper has identified how eight central aspects of kit preparation design are linked to kit quality of kit preparation. From the three case studies, several links by which to support kit error prevention and correction related to kit preparation were presented and discussed.

The findings suggest that to prevent kit errors, the picker's job should include assembly tasks, and similar-looking components should be stored separately. A single-kit policy removes the risk of sorting mistakes, and fitted slots in the kit container can promote quality. With batching, the order in which the kits should be filled should be obvious. If the applied storage packaging requires much handling, then it is important to consider how the packaging can be discarded effectively to reduce disturbances. The picking information system is important for preventing kit errors and handling deviations. To facilitate kit quality correction, the kit preparation workspace should be located close to the assembly process, and feedback from assembly regarding kit quality corrections should be swiftly considered at the kit preparation.

The paper contributes to literature by providing insights about how kit quality can be supported. Furthermore, the paper is of high relevance for practice, where little knowledge is available for how to deal with kit errors related to kit preparation.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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