QUALITY PROBLEMS IN MATERIALS KIT PREPARATION

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Increasing customisation, together with a focus on assemblers' value added time, inflates the number of component variants required in assembly, and drives implementation of kitting processes. Practice indicates that current kitting process designs exhibit quality problems, but research is scarce concerning which problems arise and why. Therefore, this paper provides a decomposition of quality in kitting processes by establishing a framework consisting of types, causes and determinants of quality problems in kitting processes. Through a multiple case study, several underlying mechanisms of quality problems and why they arise were revealed, thereby extending the current frame of knowledge.

Keywords: Kitting, Sequencing, Picking quality

1. INTRODUCTION

Increasing customisation inflates the number of component variants required in assembly operations (Boysen et al., 2009). Together with shortened product life cycles and ever more volatile markets this puts higher requirements on flexibility of the manufacturing and materials supply systems and drives the implementation of mass customized, mixed-model assembly. In such environments, where variants are numerous and the assembly situation is complex, materials preparation processes are introduced to shorten assembly times, facilitate assemblers' cognition, and increase the space efficiency at the assembly line (Wänström and Medbo, 2009). This has led to the materials feeding principle of kitting being recognised as one of the main principles for preparing and supplying components to assembly lines (e.g. Hua and Johnson, 2010; Caputo and Pelagagge, 2011). According to Bozer and McGinnis (1992), a kit is "a specific collection of components and/or subassemblies that together (i.e., in the same container) support one or more assembly operations for a given product or shop order".

If kitting is to be effectively utilised, the operations associated with the preparation of kits needs to be appropriately designed, considering the additional man-hour consumption introduced in the supply system, and designed in order to ensure the correct content in each kit (Hua and Johnson, 2010). Incorrect kit contents can result in production delays, quality costs of correcting the kit, and deficient product quality. Practice as well as research report quality concerns in regard to kitting, and highlight causes of quality problems (Bryznér and Johansson, 1995), but research is scarce regarding quality levels for different kitting process designs and regarding the mechanisms behind kitting quality problems. Therefore, the purpose of this paper is to explore which factors in the kitting process design that affects the quality outcome. Pursuing this purpose aims at attaining a decomposition of the quality implication in kitting processes through identification of types of quality problems in the kitting process, and their related causes and determinants. This is done in order to establish a framework for interpreting the quality concept in materials kitting and thus contribute to the knowledge area.

A *determinant* is a factor in the design of the system or picking process that, under certain conditions, creates a phenomenon, i.e. a *cause*, which can result in a quality problem of a certain *type* occurring. The definition used for a quality problem in this paper is any deviation from specification observed in the completed component aggregates being delivered to assembly from the materials preparation process.

2. THEORETICAL FRAME OF REFERENCE

This section presents earlier research relevant to quality outcome of the kitting process, and ends with an analytical framework. *Materials kitting* is in most cases designed as a picker-to-part order picking system (Brynzér and Johansson, 1995). As concluded by De Koster, et al. (2007), research on this type of order picking systems is scarce, and Gu et al. (2010) points at the gap between published research and practice on warehouse design and operations, requesting collaborations between researchers and practitioners. Research on designing order picking and kitting systems rarely considers the quality outcome of the kitting process.

Brynzér and Johansson (1995) considers quality in kitting systems from a performance measurement perspective, denoting the proportion of correctly performed picking operations to total number of picking operations as "picking accuracy". Frequent *causes* of quality problems are identified from a multiple case study. Having mixed components in a batch, storing similar components adjacently, interruptions of the picking procedure, inappropriate exposure of components, confirming completed pick of another component, reading misinterpretations, inappropriate materials exposure incorrect conception of the product structure, and mimicking another picking operator are highlighted as typical causes to quality problems. Also Park (2012) defines picking accuracy as the percentage of picking lines performed without error and propose a categorisation of decisive factors for the quality outcome, i.e. *determinants,* in the categories human, equipment, material, method and environment.

Joshi et al. (2002) treats quality problems in kitting of components for Printed Circuit Board assembly, using simulation to identify improvement opportunities. Kitting quality is assessed through measuring the proportion of kits to total number of kits containing parts deviating from specification. Quality problem *types* identified include under and over issue of components, incorrect issue of components, issue of improperly prepared components, backorders, and missing items at the assembly line.

In-depth reasoning connecting picking accuracy to kit-system designs is presented in Brynzér and Johansson (1995). Assigning the task of picking to the assembly operator is stated to increase picking accuracy. The batching policy is identified as a determinant for picking accuracy. For example, preparing kits in large batches increases complexity in the picking operations, thus also in the picking information, which affects picking accuracy. Storage policy is mentioned as a determinant to picking accuracy, in addition to the storage packaging types used at the picking station. Using a printed picking list often results in experienced picking operators disregarding the information, due to the information commonly being designed for inexperienced operators. Product design changes and inaccurate perception of the picking procedure then becomes problematic.

Relations between picking accuracy and picking information systems are commonly encountered in literature (e.g. Jane and Laih, 2005; Caputo and Pelagagge, 2006), although as a part of a wider line of reasoning. In ten Hompel and Schmidt (2007), picking error percentages are listed for different picking information systems. Hanson (2012) considers the relation between kitting process localisation and quality, and finds that proximity mitigates the consequences of picking errors, as replacing an incorrect component requires less time.

In conclusion, knowledge from literature on the quality implication in materials kit preparation has been merged into a conceptual model, displayed in figure 1, which constitutes the analytical framework utilised in this study.

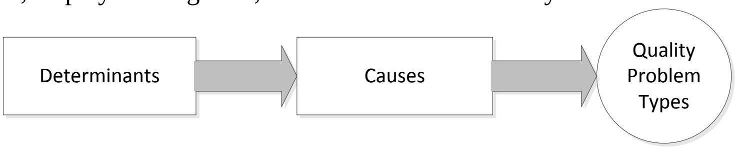

Fig. 1. The model used for conceptualising the literature, and used as an analytical framework in the study.

3. METHODOLOGY

Empirical data was collected from three case companies (comprising 9 kitting systems) in the automotive industry through semi-structured interviews. Based on the theoretical frame, the same interview guide was used for all interviews. Topics of discussion were system description, encountered quality problems, perceived reasons for problems occurring, consequences of quality problems and picking information system use and function. The interviewees were four industrial engineers, one at case company A and C and two at case company B, responsible for the design and operations of the kit preparation processes, and a logistics department group leader at case company C, managing the picking operations on the shop floor. Allotted time for each interview were approximately one hour, where the interview was voice-recorded, transcribed and sent to the interviewees for verification. Two researchers participated in each interview. During analysis of the data, the transcriptions were decomposed into categories, based on the frame of reference. Secondary data, in terms of descriptive data such as layouts and process characteristics, were partially collected during the interviews and partially supplemented afterwards. The researchers had previously been visiting the companies and were familiar with the kitting processes at the companies. During the visits, direct observation of the processes was conducted, where notes, photographs and video recordings were taken, accompanied by guided explanations by the company representatives.

Selection of cases was based on acquiring input from different contexts and system designs, e.g. number of components per kit and picking information system in use, in order to cover such design options in the intended framework. In case company A, the kits included very few components, one to four, but this is still considered as kitting, as they are sequenced and intended for a particular product in the final assembly schedule (Bozer and McGinnis, 1992). Hence, the results presented in this paper are distinguishable for each case, thus treating the situation within each case separately, rather than conducting a comparison across cases. However, similarities and differences between cases are considered in the discussion chapter, emphasising general aspects of the quality implication within the contexts of the case companies, and aspects unique for a specific context.

4. RESULTS

This section first describes the context and process design for each case, followed by the observed quality problems, presenting the types, causes and determinants of quality problems identified.

4.1. Case descriptions

Case company A is manufacturer of chassis and cabs for heavy-duty vehicles, using kits to supply the cab assembly line. The kit preparation processes are located in a separate area, away from the assembly line, and are having a separate goods reception area. Custom designed picking packages are used, having compartments where one or several compartments are allocated for a specific end product. Four of the kitting stations were studied in detail and discussed in the interviews. Their general characteristics are presented in table 1 below.

Table 1. Kitting process characteristics at case company A.

Station description	Tray Kitting	Fixture Kitting	Two Part Seq.	Shelf Kitting
Kits in batch	4	15	8	3
Components in kit	3	1	2	4
Part numbers at station	32	19	12	19
Component characteristics	Large, solid, heavy	Very large, flat, light	Large, flat, light	Varied
Similarity between part numbers	High	High	High	Low
Storage packaging type(s)	Pallets	Plywood boxes	Pallets	Pallets and plastic containers
Materials exposure	Pallets in facade on sliders	Boxes on floor opened on two sides	Pallets on floor	Pallets in façade on sliders, pallets on floor, boxes on shelf
Job role of picking operator	Dedicated picker on rotation scheme	Dedicated picker on rotation scheme	Dedicated picker on rotation scheme	Dedicated picker on rotation scheme
Location of picking station	Separate area	Separate area	Separate area	Separate area
Picking information	Printed labels	Printed labels	Printed labels	Printed labels
Quality level [PPM]	409	364	23	N/A

Case company B produces automobiles and has kitting processes located next to the served workstation at the assembly line, and in a separate area where kitting of large components is conducted. For the kitting at the assembly line, material arrives by tugger trains and custom pallet carriers in pallets and plastic boxes. The kitting operator delivers completed picking packages to the assembly stations. The processes in the separate area are supplied with pallets by forklifts and plastic boxes by tugger trains. The completed picking packages are delivered by tugger trains. General characteristics for the three studied processes are displayed in table 2.

Case company C is a manufacturer of heavy-duty vehicles and has kitting stations located in a separate area as well as next to the assembly stations. Completed picking packages are delivered by a tugger train, while the kitting operator delivers completed packages to the assembly stations for kitting stations next to the assembly line. The company has recently changed from paper picking lists to pick-to-light systems for the majority of their materials preparation processes. General characteristics for the studied kitting processes are found in table 3.

Table 2. Kitting process characteristics at case company B.

Station description	14-Batch Kitting	10-Batch Kitting	Large Part Sequencing
Kits in batch	14	10	10
Components in kit	8-10	8-10	1
Part numbers at station	~70	~80	~30
Component characteristics	Small/medium, light weight	Small/medium, light weight	Large, medium weight
Similarity between part no.	High for some	High for some	Very high
Storage packaging type(s)	Pallets, plastic boxes	Pallets, plastic boxes	Pallets
Materials exposure	Tilt-mechanism on pallets	Tilt-mechanism on pallets	Pallets in façade
Job role of picking operator	Dedicated picker on rotation scheme	Dedicated picker on rotation scheme	Dedicated picker on rotation scheme
Location of picking station	Next to assembly line	Next to assembly line	Separate department
Picking information	Pick-to-light, place-to-light	Pick-to-light, place-to-light	Pick-to-voice
Quality level [PPM]	N/A	N/A	21

Table 3. Kitting process characteristics at case company C.

Station description	List Kitting	Light Kitting
Kits in batch	3	3
Components in kit	6	10
Part numbers at station	~30	~30
Component characteristics	Large, medium weight	Small/medium size, light weight
Similarity between part no.	Low	High
Storage packaging type(s)	Pallets	Pallets, plastic boxes
Materials exposure	Pallets on floor	Pallets in façade, boxes on shelf
Job role of picking operator	Dedicated picker on rotation scheme	Dedicated picker on rotation scheme
Location of picking station	Separate department	Next to assembly line
Picking information	Paper picking list	Pick-to-light
Quality level [PPM]	N/A	N/A

4.2. Types, causes and determinants of quality problems at the case companies

This section is organised by case company, where the reasoning of the interviewees is presented according to the quality problems the companies encountered in their kitting processes, connected to probable or possible causes and determinants in the system. For each company, each situation and quality problem encountered is numerated, and each line of reasoning for certain situations has been separated. These identifiers are used in Table 5 to relate the instances of quality problems to the cases.

Case company A

A1. The most common picking error encountered at case company A was that an incorrect component was included in the kit, in place of the specified component. This could arise due to inattention of the operator, but the materials supply to the kitting process, specifically the placement and consistency of the material at the kitting station, was emphasised. There had been instances where: a) a pallet had been misplaced by materials supply during replenishment; b) pallets containing mixed components; c) pallets containing incorrect component from supplier. This can lead to the operator unassumingly picking the incorrect component. Concerning pallets containing incorrect components, this could either occur already at the supplier, passing unnoticed through goods receiving, or because the pallet was marked or identified incorrectly upon arrival.

A2. Materials supply could be delayed due to queues built up at the AS/RS output conveyor, resulting in components not being available at the kitting station. Occasionally, the kit batch needed to be delivered, although components were omitted, resulting in incomplete picking packages being delivered to the assembly line. However, the component was marked as backlog and the assembly line was notified of the omitted part, which was delivered separately as soon as it was available.

A3. A tendency of forgetting placing a component in a compartment was perceived for situations where the picking package is constituted by several compartments, and more than one component is specified for a compartment, since the compartment appeared completed due to a component already being placed there.

A4. Instances of components in interchanged positions in the picking package, which was difficult to detect at the kitting station as the correct components had been picked at batch level, but misplaced within the batch.

A5. Interchanged positions of kit batches, where the operator completes the batch backwards, resulting in the entire batch being out of sequence.

A6. Deliveries from the kitting station could occasionally be out of sequence. Disturbances or not following standard was perceived as the main causes. Having many picking packages active in the system was perceived to result in out of sequence delivery.
A7. Kit supply lateness, resulting in assembly line stoppage due to kits being unavailable.

Case company B

B1. An incorrect component in a kit was considered the most common quality problem, most often due to: a) the operator collects a component from another location than specified; b) the storage packaging containing mixed components. This could either occur already at the supplier, passing unnoticed through the goods receiving and materials supply function, or the materials supply could, although less commonly, replenish to an incorrect storage location.
B2. Components could become mixed due to parts being returned to an incorrect location during the picking process. This often occurred when the operator picked an excessive number of parts from the storage package, thus having to return the excessive parts to the storage packaging. This problem was perceived to occur more frequent if similar components were stored next to each other in the material façade.
B3. A cause of components being omitted was unavailable material at the kitting station during the picking cycle. This occurred when the operator worked ahead of schedule. If the operator then continued with the next picking order, another operator could occasionally deliver the picking packages, unaware of the shortage. The pick-to-voice system had a functionality where the picking operator could inform the system that a certain component was not available, thus marking it as backlogged. Once the picking cycle was complete, the system re-informed the operator of the backlogged components, allowing these to be added to the picking package before delivery to assembly if available at the time of cycle completion.
B4. Pickers being disturbed because storage packaging required significant handling efforts was strongly emphasised as having a harmful effect on the quality outcome, as: a) storage packaging required significant handling, causing interruption and resulting in the operator forgetting in which position to place components or what operation that were next to be performed; b) handling of inner packaging or empty packages required the operator to walk a significant distance, the probability of a picking error increased.
B5. An aspect mentioned in the interview was the probability of the assembly operator picking the wrong component during the assembly process. Hence, in the case of several kits being sequenced to assembly in a picking package, there is a risk that an incorrect component is assembled onto the end product, even if the picking package has been prepared correctly.
B6. Complexity of the picking operations was perceived to increase with the number of unique components.
B7. It had also been noticed that smaller components were more disposed to incorrect picking than larger components, as well as similar components stored close to each other in the material façade.

Case company C

C1. An incorrect component in a kit was perceived as the most prevalent quality problem, for processes were paper picking lists was used. Misreading the picking list was perceived as the primary cause.
C2. For processes using pick-to-light systems, picking an incorrect quantity of a component was perceived as the most common quality problems, where: a) assuming an incorrect number of components required was perceived as the most probable cause; b) the operator returned superfluous parts after actually reading the display, but components were occasionally returned to incorrect storage package, thus mixing the contents.
C3. During introductions of new products, hence new components to be picked at the station, a tendency of overlooking these components was apparent, both in the picking, materials supply and assembly operations.
C4. Picking operator disturbances was emphasised as a probable cause, e.g. forgetting picking information due to a conversation with a colleague.
C5. Inappropriate positioning of the lights of the pick-to-light system, resulting in that the operator could misinterpret which storage position was indicated.
C6. When using paper picking lists, the batching policy was perceived to be of significance, where a larger batch increased the complexity and risk of mistakes. Using place-to-light mitigated the complexity.
C7. A higher number of unique components increased the complexity of the picking operation, which was problematic when using paper picking lists, but irrelevant when using pick-to-light.
C8. Instances where storage packaging had been misplaced had been encountered, resulting in the incorrect component being picked, as the picking information, particularly in pick-to-light processes, indicates location rather than component.
C9. Sensitive components were perceived as prone to damage during the picking or materials supply.

5. DISCUSSION AND CONCLUSIONS

In section 5.1, identified quality problems by the case companies are compared against the existing literature discussed in section 2. Subsection 5.2 connects types, causes and determinants of quality problems, using the analytical framework introduced in section 2, and subsection 5.3 discusses the contribution of the paper.

5.1. Quality Problems Identified by the Case Companies

Ten unique quality problem types were identified in the cases. A compilation of the types of quality problems identified is found in table 4. The quality problem types identified in literature has been assigned a new denotation in order to reflect the perspective of the researchers and the nomenclature encountered in the interviews.

Table 4. Quality problem types recognised in the cases. The bold line separates types found in literature.

Quality Problem Type	**Frame of Reference Denotation**	**Description**	**Case Company**		
			A	**B**	**C**
Incorrect component	Incorrect issue of components	Another component than intended is included in the picking package	x	x	x
Superfluous components	Over issue of components	Additional instances of a part number are included in the picking package	x	x	x
Insufficient number of components	Under issue of components	Too few instances of a part number are included in the picking package	x	x	x
Known omitted component	Backorder	A component is omitted from the picking package due to currently being unavailable in preparation process	x	x	
Missing component	Missing items at the assembly line	A component is not present in the picking package	x	x	x
Incorrectly positioned component	Issue of improperly prepared components	A component is incorrectly positioned or oriented in the picking package, deviating from specification			x
Interchanged components		Two components are interchanged, correct components are picked but placed in incorrect kits or sequence	x	x	x
Kit supply lateness		The picking package is not available at the assembly station at the time the components are required	x	x	x
Damaged component		A component is damaged, hence unusable in assembly, and included in the picking package	x		x
Incorrectly sequenced kits		Kits are in incorrect sequence in the picking package or consecutive picking packages are out of sequence	x		x

All six quality problem types identified from literature were also identified in the cases. In addition, four more quality problem types were identified. Despite the study in Joshi et al. (2002) was conducted in a PCB-assembly system context, where the kits were used at a highly automated assembly line, in contrast to the automotive industry, more than half of the problems found at the case companies was also found by Joshi et al. (2002). This point at similarities between the two contexts and between components of different types.

5.2. Causes and Determinants of Quality Problem Types Identified by the Case Companies

This section summarises the main causes and determinants for quality problems found in the cases (table 5). In total, 21 determinants were identified from the cases where table 5 displays the relation between these determinants, their associated causes to quality problems, and the quality problem types.

The distinction made between determinants and causes became apparent during the literature review as a necessity for interpreting why the different quality problems arise. There is indeed a difference between the operator being disturbed, hence picking the incorrect part number, and that the disturbance comes of an empty package being discarded. Even though the disturbance causes the problem directly, the packaging type, the organization, or the station layout, are design aspects that create this situation, and are thus decisive for the quality problem, i.e. determinants for the quality outcome. From table 5, it is clear that in most cases there are more than one determinant connected to a specific cause. This was deduced from the fact that, in most cases, the interviewees proposed conditional AND statements regarding why a particular situation arose.

Table 5. Determinants, causes and types of quality problem derived from the study.

Determinant	Associated cause	Associated quality problem type	Identifier in Sect. 4
Reliability of materials supply to kitting process	Incorrect mark-up or packaging from supplier	Incorrect component	A1b, A1c, B1b
	Incorrect replenishment to kitting process	Incorrect component	A1a, A1b, C8
	Delayed supply to kitting process, hence components unavailable during cycle	Known omitted component	A2
		Missing component	B3
		Kit supply lateness	A2, A6, A7
Work organisation	Operator works ahead of tact resulting in shortage, order is then completed without components but is delivered to assembly by another materials handling operator	Missing component	B3
Synchronisation with tact			
No. of picking packages in material flow			
Materials supply to assembly	Picking packages retrieved and delivered out of sequence	Incorrectly sequenced kits or picking packages	A5
No. of picking packages in material flow			
Storage packaging type	Operator forgets next picking operation due to intermittent handling of packaging, particularly if long walks to discard point	Incorrect component	B4a, B4b
		Superfluous components	
Kitting station layout		Insufficient no. of components	
		Interchanged components	
No. of part numbers at kitting station	Complex situation when using paper picking lists, hence cognitive misinterpretation	Incorrect component	B1a, B6, C1, C7
Picking info. system type			
Similarity between parts	Mixed pallet contents due to incorrect return of components to storage packaging	Incorrect component	B1b, B2
Storage policy			
Similarity between parts	Picking from incorrect container, due to similar components are stored closely	Incorrect component	B7
Storage policy			
Picking package design	Incorrect assumption of kit being complete as components are already apparent in kit	Insufficient number of components	A3
No. of components in kit			
Picking sequence	Two part numbers are placed at each other's destination, not prohibited by picking information system	Interchanged components	A4
Functionality of picking information system			
Picking sequence	The batch is completed backwards, hence delivered out of sequence within the batch	Incorrectly sequenced kits or picking packages	A5
Picking package design			
Picking information type	The operator assumes incorrect number of parts due to an order of regular parts in non-standard quantity. If the error is noticed, parts could be returned to incorrect location	Superfluous components	C2a
Order content consistency		Insufficient no. components	C2a
		Incorrect component	C2b
Picking package design	Components can be collected from incorrect kit during assembly, due to presence of several kits in the picking package	Incorrect component	B5
Reliability of final assembly			
Material supply to assembly	Materials supply retrieves packages with components remaining, unaware of contents, or assembly operator neglects certain components upon non-recognition	Missing component	C3
Reliability of final assembly			
Order content consistency			
Communication type	Operator forgets next picking operation due to interruptive communication	Incorrect component	C4
Information system setup	Incorrect component is collected due to ambiguous indicator positioning	Incorrect component	C5
Material façade design			
Picking package design	Component is placed in incorrect kit due to ambiguous and numerous placing locations	Incorrect component	C6
Picking info. system type			
Component characteristics	Fragile components can be damaged during picking, transport or assembly	Damaged component	C9
	Small components more difficult to identify	Incorrect component	B7

5.3. Contributions to Research and Practice

This subsection emphasises three of the determinants in table 5: *Reliability of the materials supply*, *Picking information system*, and *Storage packaging type*. These were considered particularly important contributions to existing theory or practice in that they both confirm and elaborate on existing knowledge or they are previously being disregarded or considered of less importance.

Reliability of the materials supply both to the kitting processes and to the assembly was by all case companies identified as a determinant for quality problems. Shortages of components at the kitting stations and delivery lateness confirm the results of Joshi et al. (2002). However, additional causes of quality problems attributed to the material supply function, which have not been highlighted in previous research, was identified in this study. The *picking information system* is in previous research identified as a determinant for picking quality (Brynzér and Johansson, 1995), which was confirmed in this study. However, the cases revealed several underlying mechanisms for the relation between the picking information system and the quality levels. For example, at case company C, a set of stations used paper picking lists, where a higher number of part numbers at the station and larger batches of kits were identified as determinants of quality problems. This was not experienced at stations utilising pick-to-light systems, pointing at a difference in how the picking operator interprets the information in the two systems. The *storage packaging type* was by case company B identified as a determinant for picking quality as it caused intermittent disturbances to the picking procedure. Brynzér and Johansson (1995) mention the storage packaging being a determinant for picking accuracy, but do not explain the causes introduced by the storage packaging.

The quality of materials kit preparation is an important aspect for industry, and scarcely treated in earlier research. This paper has derived a decomposition of quality in kitting, structured in types, causes and determinants of quality problems. Additionally, the paper has identified additional aspects of the kitting process and the production system which previously has not been emphasised in published literature, e.g. the materials supply to the kitting process and number of part numbers at the kitting station. However, the empirical basis is at present limited, implying the possibility of additional problems, causes and determinants. Yet, in its current state, a framework is provided by the paper for practitioners to consider when designing kit preparation processes, and contributes to existing knowledge through structuring quality issues in materials kit preparation into a framework of determinants, causes and types.

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