CHALMERS
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Materials preparation handbook

Guidelines for choice of materials preparation design

PATRIK FAGER

Division of Supply & Operations Management
Department of Technology Management & Economics
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Division of Supply and Operations Management
Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000
www.chalmers.se

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Patrik Fager
Department of Technology Management and Economics
Chalmers University of Technology

ABSTRACT

Materials preparation is increasingly applied with mixed model assembly as means of support to the assembly process. With materials preparation, components are sorted at a picking area before reaching the assembly process. This is required when, for example, materials are supplied to the assembly process by kitting or part sequencing approaches. When presented to the assembler, prepared materials shorten the walking distance and simplifies the search for components in the assembly process compared to other approaches, and promotes the assembly's performance. However, to best support the assembly process, the materials preparation must be carried out cost effectively with satisfactory quality, flexibility, productivity, and ergonomics, with respect to the current context.

Previous research and practitioner experience has shown that the materials preparation design can greatly affect the performance outcome. There is a multitude of decisions involved with the choice of materials preparation design, and choosing an appropriate design that fulfils the performance expectations with respect to the context can be a complicated task. The aim of this handbook is to present previous research and practitioner knowledge regarding how to design materials preparation processes in assembly systems, and to consolidate the various decisions associated with materials preparation design into a framework that can be applied by practitioners and academics dealing with materials preparation design.

The handbook presents the various aspects related to the design, context and performance of materials preparation, in form of guidelines for how these aspects may be considered in the design process. The guidelines focus on how to design manual picking processes where a single worker carries out the picking work. The context in which the guidelines are presented is mixed model assembly, but much of the content would also find applicability in other contexts, for example warehouse order picking in distribution or e-commerce settings. The guidelines presented in the handbook are based on the outcome of a research project which was a joint venture between academia and industry, and included partners from both the manufacturing and distribution sectors.

The perspective taken on the design problem of materials preparation processes in the current handbook is to view the design as a set of design variables, for which the aim is to find suitable settings to achieve the desired performance outcome. For each design variable, a number of typical options are presented and the effects on the performance, and the influence of the context when making the choice, are explored and discussed based on the findings from the research project.

The first chapter of the handbook introduces the scope and aim of the book, and provides an overview of the chapters to come. In the second, third and fourth chapters, the various aspects and typical options with respect to the materials preparation performance (chapter 2), context (chapter 3), and the design (chapter 4) are presented and discussed. In the fifth chapter, a design process is outlined and guidelines for achieving the performance objectives by means of the design and with respect to the context are provided. In the sixth chapter, a set of examples of materials preparation design from industry and from the research studies are presented to give a hands-on view of what can be done and what should be avoided. In the final chapter, the book is concluded along with an outlook of future opportunities and challenges related to materials preparation design.

This handbook is intended for readers interested about the design of picking systems. The book is written for readers from both academia, for example researchers or students, and from industry, for example engineers, managers or consultants. The book's structure permits easy access to referential reading about various aspects of the materials preparation design, and although the book certainly could be read from start to finish, it would serve the reader to start with a set of questions already in mind. Materials preparation is carried out for supporting the assembly process, and this book supports the decision process when choosing a materials preparation design.

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Patrik Fager

About the author:

Patrik is a PhD student at the Department of Technology Management & Economics at Chalmers University of Technology.

He conducts research about production logistics, with a focus on materials handling and order picking applications in mixed-model assembly systems.

Department of Technology Management & Economics
Chalmers University of Technology

1. Introduction

1.1. Background

> ***There is a multitude of decisions associated to the materials preparation design that can support the performance outcome of materials preparation.***

In mixed-model assembly, there is often a multitude of component variants and the materials supply to assembly is crucial. Here, using line stocking as the materials supply principle – meaning to present all different variants alongside the assembly process – usually results in long walking distances for the assembler and much time spent searching for the right components. Two alternative materials supply principles to line stocking which are increasingly applied in industry are kitting – meaning to sort the component variants needed for each assembly object into a single package – and sequenced part supply – meaning to sort components by both assembly object and product family.

Research has shown that using kitting and sequenced part supply instead of line stocking leads to substantial reductions in the amount of storage space needed at the assembly process – as only the components needed for the next assembly object are presented for the assembler – and that the assembler's work is facilitated by it being easier to find the correct components. Applying kitting or sequenced part supply requires materials preparation to be performed in the materials flow, typically organised as various workspaces that houses a part of the product structure and where the needed materials are collected by means of manual picking work.

Research has shown that using materials preparation can require substantial resources – including labour and floor space – and that quality problems with the prepared materials, stemming from errors during the materials preparation process, can have substantial negative impact on the production system. In mixed-model assembly, product life cycles are also often short and there are high demands from customers on product customisation, why the materials preparation must be capable to adapt quickly and efficiently to maintain performance. Furthermore, materials preparation is today still mostly performed by manual labour and can involve heavy lifts and repetitive picking work tasks.

There is a multitude of decisions associated to the materials preparation design that can support the performance outcome of materials preparation. The aim of this handbook is to present previous research and practitioner knowledge regarding how to design materials preparation processes in assembly systems[1], and to consolidate the various decisions associated to materials preparation design into a framework that can applied by practitioners and academics dealing with materials preparation design.

The framework is based around the idea that the materials preparation design must be chosen with consideration to the context in which the materials preparation is performed, and that the aim of the design is to achieve desired performance levels of quality, flexibility, productivity, ergonomics, and cost.

The handbook is one of the results from a research project that spanned 30 months between 2014 and 2016 and was carried out under the title "Design of Materials Preparation Processes". The research project was a joint collaboration between Chalmers University of Technology, Scania, Volvo Car Corporation, Volvo AB, VBG truck equipment, Schenker Logistics and Bulten. The colloborative parties of the research project have jointly contributed to the guidelines presented in this handbook.

The intended readership of this handbook are individuals involved with in-plant logistics in mixed-model assembly systems, but a wider audience interested in warehouse order picking in other contexts, for example distribution, may also find parts of the handbook to be of value.

1) The guidelines are presented in the context of assembly systems, but may be applicable in any system where materials are arranged in accordance with customer requirements in a similar fashion, as in e.g. warehousing and distribution settings.

1.2. Aim

The aim of this report is to present previous research and practitioner knowledge regarding how to design materials preparation processes in assembly systems, and to consolidate the various decisions associated to materials preparation design into a framework that can be applied by practitioners and academics dealing with materials preparation design.

1.3. Scope

This handbook deals with the design of the work-space where materials preparation is carried out and the contextual aspects of the production system and the supply chain that may affect the design decisions of that workspace. **The reader may expect the following from the handbook:**

- Descriptions of various options for materials preparation design
- Design guidelines for single-zone (one worker) materials preparation workstations
- Estimates of the performance effects from various design options
- Descriptions of important context factors and their interaction with the design
- Considerations for choosing among options of materials preparation design variables
- Examples from industry of materials preparation design
- Summaries of research studies on materials preparation

The guidelines presented in the handbook also **assumes the following prerequisites about the situation to be met:**

- Manual labour is involved and components are handled with one or both hands. Although various semi-automated design options are treated in the handbook – regarding to for example lift supports – these are treated as a support to the manual work. Within the scope of this handbook, control is always manual and power is either manually or mechanically generated[2].
- The type of materials preparation has been decided (e.g. kit preparation). The guidelines are primarily intended for the design of kit preparation or part sequencing processes for materials supply to mixed-model assembly processs. The guidelines may be applicable to other forms of picking processes, but the handbook does not cover those generalisations. The reader is asked to exercise his or her own best judgement when generalising to other contexts.
- The component variants to be managed by the process have been selected.
- Information about context factors is available to the designer.

1.4. Summary of chapters

1.4.1. Chapter 1 – Introduction

The first chapter presents the background (section 1.1), aim (section 1.2) and scope (section 1.3) of the handbook. Chapter 1 also and provides an overview of the report structure the contents (section 1.4).

2) Control refers to steering and choice of what component to pick and where to place a component being handled. Power refers to the force required to handle the component being picked or placed. For more details, see Goetschalckx and Ashayeri (1989), "Classification and design of order picking", Logistics World, p. 101.

1.4.2. Chapter 2 – Materials preparation performance

Chapter 2 explains materials preparation performance and the five materials preparation performance objectives. In summary, materials preparation performance concerns the effects that the materials preparation process has on the assembly system in terms of quality, flexibility, productivity, ergonomics and cost. Within the scope of this handbook, a specific materials preparation design, in a certain context, results in a certain performance in terms of the five performance objectives. Chapter 2 presents definitions of these five performance objectives and explains various approaches for estimating them. The chapter is organised with each of the materials preparation performance objectives:

- Quality (Section 2.1)
- Flexibility (Section 2.2)
- Efficiency (Section 2.3)
- Ergonomics (Section 2.4)
- Cost (Section 2.5)

1.4.3. Chapter 3 – Materials preparation context

Chapter 3 explains what the materials preparation context is and how the context should be considered when the materials preparation design is chosen. In brief, the context of the materials preparation process are factors in the production system that sets what design options can be chosen, or that have a direct influence on the performance. In common for all factors in the context is that they are outside the control of the materials preparation designer. The most relevant factors in the context to consider in the design process, presented in full in Chapter 3, are the following:

- Component characteristics (section 3.1),
- Picker's experience level (section 3.2),
- Variants per component family (section 3.3),
- Floor space availability (section 3.4),
- Shift capacity and time horizon (section 3.5)

1.4.4. Chapter 4 - Materials preparation design

In Chapter 4, the materials preparation design variables and their different options are presented. The chapter presents the materials preparation design as nine different design variables, which each have a set of options which can be chosen by the materials preparation designer. For each option, the relevant factors in the context and the performance effects which can be expected from choosing the option are discussed. The nine materials preparation design variables and the sections in which they can be found are as follows:

- Planning and control (4.1.)
- Location (section 4.2),
- Work organisation (section 4.3),
- Policies (section 4.4),
- Layout and movement pattern (section 4.5),
- Storage packaging (section 4.6),
- Picking package and carrier (section 4.7), and
- Materials handling equipment (section 4.8),
- Picking information (section 4.9)

1.4.5. Chapter 5 – Choice of materials preparation design

In Chapter 5, the performance objectives, the context factors and the design variables are consolidated into a framework that shows what options to use to achieve the various performance objectives.

1.4.6. Chapter 6 – Examples of materials preparation design

The final chapter presents ten examples about materials preparation design from industry and highlights results from some of the research studies performed in the research project. The reader is referred to these examples throughout the handbook at places where aspects associated with the examples are discussed.

2. Materials Preparation Performance

For the materials preparation to fulfil the requirements of assembly, the materials preparation needs to be performed without errors so that prepared materials are delivered in accordance with the assembly schedule (quality objective). The materials preparation workspace must also be capable of adapting quickly and efficiently to changes in the production system so that performance does not deteriorate and the costs of making changes to the design does not escalate (flexibility objective).

The materials preparation should also be performed efficiently in terms of picking efficiency and space efficiency, to avoid excessive lead times and avoiding locking up space in the production facility (productivity objective). The physical work area, the equipment and the work tasks must be designed with the worker in mind as a safe and non-weary work environment (ergonomics objective), and the designer must consider the investment and operational costs when choosing design (cost objective).

This chapter presents the five materials preparation performance objectives:

1. Quality
2. Flexibility
3. Productivity
4. Ergonomics
5. Cost

The chapter is structured in five sections, where each section deals with one performance objective. For each performance objective, their meaning and metrics are explained in terms how they influence the materials preparation performance, and independencies between various objectives are discussed.

2.1. Quality

Materials preparation quality is the degree to which a completed delivery of materials conforms to the requirements of the customer.

In an assembly system, the customer of the materials preparation process is the assembler at the assembly process. The materials preparation quality performance is the degree to which the prepared materials meet the requirements of the assembler, in terms of the correct components according with the Bill of Materials (BoM) and the timeliness of the delivery. There are two main types of requirements on the prepared materials:

❶ **Basic requirements:** The prepared materials must conform to the assembly schedule and components in the BoM which are needed at the assembly station. The ‘basic requirements’ hence refer to the correct contents and timeliness of prepared materials delivery.

❷ **Performance requirements:** The prepared materials should reduce the amount of waste at the assembly process compared to other means of materials supply. The ‘performance requirements’ thus refer to additional criteria that improves the situation in assembly, beyond the contents being correct. This includes, for example, the position and orientation of components within the delivery package, which, when present, facilitates the assembler's work.

The materials preparation quality can be regarded as the inverse of the amount of deviations from the requirements posed by assembly that are observed in the prepared materials, which here is termed the 'preparation accuracy.' Preparation errors lowers the preparation accuracy and can arise from various reasons, for example due to errors in the picking work or in the handling of the prepared materials, or even from errors the BoM. The preparation accuracy and the typical errors encountered in a materials preparation process are treated in more detail in section 2.1.1.

Different types of preparation errors leads to different costs to the system. For example, the wrong component variant included in the delivery may lead to the wrong component variant being assembled, which in turn, if detected at all, will require substantial rework to fix at a later point, incurring a substantial cost to the system. In contrast, if one additional component of a component variant is included in the package, it can simply be left in the package to return to the preparation area with the materials supply, incurring a significantly smaller system cost than picking the wrong component. In this sense, some preparation error types are more severe than others, why in addition to the preparation accuracy, it also important to account for the 'quality adjustment cost,' which represents the cost of correcting preparation errors. The quality adjustment cost is treated in more detail in section 2.1.2.

2.1.1. Preparation accuracy

Any error in the prepared materials that is observed during the preparation or at the assembly process, including late deliveries, are instances of preparation errors, which sum up to the preparation error level.

When a preparation error is detected in assembly, it has to be resolved before the assembly can continue. Different types of errors are rectified in different ways, using different solutions. Often there are formal routines in place for how the error is supposed to be rectified, but in some situations informal routines can develop over time which are used in place of the formal routines.

Table 2.1: A preparation error type taxonomy and their typical solutions.

Preparation error type	Description	Typical solution
Wrong component	Another component than intended is included in the picking package in place of the correct component	The correct/missing component has to be collected at the preparation area, or supplied be from the warehouse, by: ● the team leader or a material handler (formal routine), or by ● the assembler who walks over to the preparation area (informal routine)
Missing component	A component is not present in the picking package	
Damaged component	A component is damaged, hence unusable in assembly, and included in the picking package	
Too few components	Too few components of certain component variant are included in the picking package	
Interchanged components	Two components are interchanged between picking packages	● Formal routine: The assembler requests the correct components for each picking package. ● Informal routine: The assembler notices the interchange and switches the components to the correct picking package
Too many components	Additional components of a component variant are included in the picking package	● The additional component(s) can be put aside or remain in the picking package, to later be transported back to the preparation area
Late delivery	The picking package is not available at the assembly process at the time the components are required	● Formal routine: Components are assembled at a later stage (if possible due to the assembly sequence) ● Informal routine: Components are cannibalised from other prepared materials packages present at the line
Wrongly positioned components	A component is wrongly positioned in the picking package (structured picking package only)	The assembler picks the component from the position it is in, checks that it indeed is the correct component and then proceeds with assembly

The different error types which can arise in preparation processes[3] and their typical procedures for rectification, including typical formal and informal routines, are presented in Table 2.1.

Different error types have different probabilities for occurring. The probability   that error type   occurs during a picking operation, depends on how the preparation process is designed and is not really possible to determine absolutely. However, if the probabilities of different error types occurring are known, the preparation accuracy $P_{accuracy}$ can be determined in accordance with equation 2.1:

$$P_{accuracy} = 100\left(1 - \frac{1}{C\sum_{i=1}^{n} p_i}\right) \qquad [2.1]$$

where,

C = Total amount of components picked
p_i = Probability of error type i occuring when an order line is completed
$i = 1, 2, 3, \ldots, n$ = index for the error types

At most companies, there is a procedure in place for reporting preparation errors, through which an estimate of the preparation error level can be derived. The procedure for reporting errors is often linked to the support function for the assembler, who can alarm the system that there is an error and then get support. The reporting of preparation errors is part of the formal routine for handling errors, why there may be a large discrepancy between what the error records show and the actual amount of preparation errors if informal routines for handling errors have been developed which are used instead of the formal routines. Additionally, even if the formal routines are followed, it is also likely that some errors are never detected.

In the formal routine, the assembly operator or the team leader writes a report when an error has been resolved, that describes what component the error concerned and what the error was. When the reports of errors related to prepared materials are summarised and compared with the total amount of parts picked in the materials preparation process, an estimate of the preparation error level can be derived. The error reports are also used as basis for a root-cause analysis to prevent the error from happening again, thereby informing the work with continuously improving the preparation process.

A key aspect for deriving the preparation error level reliably is that the error reporting procedure allows any detected errors to be reported quickly, requiring a very small time investment by the assembly operator, who detects the error, or by the team leader. A difficult or time consuming procedure for creating error reports will increase the likelihood of the error not being reported.

Usually, the preparation errors that appear in the error reports are errors that require some effort to correct. It has also been learned over the course of the research project that the location of the materials preparation workspace can influence how many errors are reported. When the location is close to the assembly process, the assemblers tend to prefer a visit the preparation area to collect the correct component to rectify the error over reporting report the error and wait for the correct component to be delivered.

2.1.2. The quality adjustment cost

The quality adjustment cost refers to all costs which arise when a preparation error is rectified. Different error types have different solutions for rectification, see Table 2.1 for details. The cost of rectifying a specific error type depends partly on what procedure is used for rectifying the error, but also on how the procedure is designed, which is part of the context for the preparation process. Each type of error requires its own procedure for being rectified, resulting in a specific quality adjustment cost. With $\mathbf{p_i}$ being the probability of error type $\mathbf{e_i}$ occurring, and $\mathbf{c_i}$ being the cost of rectifying error type $\mathbf{e_i}$, the quality adjustment cost $\mathbf{C_{adjustment}}$ for performing picking operations in the process is given by equation 2.2:

$$C_{adjustment} = C\sum_{i=1}^{n} p_i\, c_i \qquad [2.2]$$

where,

c_i = the rectification cost for error type e_i

The typical solutions for the error types listed in Table 2.1 can be grouped into three principally different types of solutions in regards to the quality adjustment cost:

❶ **Solution type I:** Correct components need to be resupplied to the assembly process, with a high quality adjustment cost. Occurs for the formal routines for correcting the error types: wrong component, missing component, damaged component, too few components or interchanged components.

❷ **Solution type II:** Errors that can be corrected at the assembly process, with a low quality adjustment cost. Examples of this type include the informal pro-

3) **The taxonomy over types of preparation errors presented in Table 1 was derived in the study: Fager et al. (2014), "Quality problems in materials kit preparation", In: *Proceedings of the 6th Swedish production symposium, September 16-18, Gothenburg, Sweden***

cedures for rectifying the error types: wrong component, missing component, damaged component, too few components or interchanged components, and the informal routine for handling late deliveries, as well as too many components and wrongly positioned components.

3. **Solution type III:** Error that area corrected after the assembly is complete, often at a rework area after the assembly process or at the customer, implies the highest quality adjustment cost. Apart from the formal routine for handling late deliveries, the third principal solution is required if any of the other error types in Table 2.1 are not rectified during the assembly.

2.1.3. Preparation error response time

A special consideration regarding the quality adjustment cost is the **preparation error response time**, which is a measure of the time from the moment when an error is detected at the assembly process until the moment the error is resolved and the assembly can continue. When an error is detected in the prepared materials at the assembly process, it has to be corrected as soon as possible to avoid complications, for example that other kits are cannibalised (i.e. components from other kits are used instead of the missing components in the kit) at the assembly process. A short preparation error response time will reduce the cost of Type I solutions and will also reduce the risk of the Type III solutions being necessary to use.

The preparation error response time is only relevant when a new component must to be collected from the preparation area, related to solution I and II and the error types wrong component, missing component, damaged component, too few components, or interchanged components (see Table 2.1 for the preparation error type descriptions). The preparation error response time could also impact the ability to handle late deliveries, as deliveries from the preparation area to assembly will have a lower response time in case the process is located closer to the assembly process if all things other being equal. In general, a response time longer than the cycle time at the assembly process will be problematic.

2.2. Flexibility

Flexibility in materials preparation refers to the ability of the materials preparation process to respond to changes that occur in the requirements from assembly, that stem from changes in the production system. There are primarily five types of changes in the production system that the materials preparation process require flexibility for handling:

1. new product introductions (new product flexibility),
2. product modifications (modification flexibility),
3. production mix changes (mix flexibility),
4. production rate changes (volume flexibility) and
5. late changes in delivery schedule (delivery flexibility). Table 2.2 presents descriptions of the five primary changes in the production system which require materials preparation flexibility, including how the requirements on the materials preparation change due the production system changes.

Flexibility concerns the ability of a system to respond to circumstances that necessitate the system to change, and the penalty in time, effort, cost, or performance of changing[4].

There are two measurements of flexibility that represent the performance of the materials preparation process regarding the five flexibility types: range and response. Central to both range and response flexibility is the concept of "effort", which refers to the cost, leadtime and organisational disruption that is associated to adapting the process to new requirements. Range flexibility is the capability range which the process is designed to handle changes within, and response flexibility refers to the effort required for handling a certain change in requirements within the capability range.

4) This definition of flexibility is based on the works of Mandelbaum and Buzacott (1990) and Upton (1995).

Table 2.2: The changes in the production system that require materials preparation flexibility and the changed requirements for the materials preparation that result from the production system changes.

Flexibility type	Change in production system	Description	Change in materials preparation requirements
New product	New product introductions	A new end product model is introduced in the production system	New component variants are added to the to the process, requiring storage in the process
Modification	Product modifications	An end product model is modified (Engineering Change Order)	A component variant is substituted for another and has to be changed in the process
Mix	Production mix changes	The demand changes for some end product models	The demand for some of the component variants change in the process
Volume	Production rate changes	The production rate is increased or decreased	The demand for all component variants in the process changes
Delivery	Late changes in assembly schedule	The assembly schedule is changed after it has been released to the assembly process	The picking information changes for the materials preparation, either before or after the preparation has started

2.2.1. Range flexibility

Range flexibility is the span of change that a process can manage without noticeable impact on the performance, with negligible cost and which requires only a small lead time to implement. The measurement unit for a given range flexibility type is expressed in the type of change which it handles. For example, as new product flexibility is the materials preparation process' ability of adding new part numbers to the process with small effort, the new product range flexibility is measured in the number of new part numbers that can be added to the process with small effort. Table 2.3 shows the definitions, units and influential factors in the design and context for the five flexibility types.

2.2.2. Response flexibility

Response flexibility is the ability of the materials preparation process to respond to the changes in the production system. This ability can be measured in the cost expense and the lead time for implementation—the effort—of making the necessary changes.

The response flexibility can depend on the range flexibility when the effort for adapting the process is different within different areas of the range. However, the response flexibility also depends on design areas which do not affect the range flexibility, where different efforts result for adapting the process from different design choices. The response flexibility is estimated by the cost and lead time of, for example, creating new picking locations in the process.

Table 2.3: The five flexibility types and the factors in the design and context that primarily influence them.

Range flexibility type	Definition	Range	Influential factors in the design and context
New product flexibility	The ability of adding new component variants to the process with small effort.	Number of part numbers that can be added	• Number of free picking locations in the storage racks and shelves • Floor space available around the preparation area for extending storage racks and shelves
Modification flexibility	The ability of substituting a part number for a new part number will small effort.	Number of part number that can be substituted	• Type of storage racks • Storage packaging • Type of picking information system
Mix flexibility	The ability to handle demand variations for individual part numbers with small effort.	Change in demand of individual part numbers that can be handled	• Storage assignment policy • Type of storage racks • Storage packaging
Volume flexibility	The ability to handle a different aggregate demand for all part numbers with small effort.	Change in aggregate demand that can be handled	• Storage capacity in storage racks and shelves • Man-hour capacity
Delivery flexibility	The ability to handle changes in the assembly schedule with small effort.	Time window before assembly within which orders can be changed	• Location • Type of materials supply to assembly

2.3. Productivity

Materials preparation productivity concerns the amount of resources required for performing the materials preparation. The primary resources of concern regarding productivity include floor space, man-hours, inventory, and equipment. The productivity is primarily determined by the following six types of efficiencies related to the various resources:

”Productivity is the effectiveness of productive effort, especially in industry, as measured in terms of the rate of output per unit of input”

❶ **Preparation efficiency:** Refers to combined resources associated with the materials preparation and the receiving assembly process. Research has shown that typical applications of kit preparation in industrial systems results in about the same total resource requirement as using line stocking would[5]. The preparation efficiency is crucial to consider when assessing materials preparation to avoid adding resource requirements to the system.

❷ **Space efficiency:** The amount of floor space required for performing the materials preparation. The location, layout and types of materials handling equipment used can have a substantial impact on the space efficiency. Furthermore, contextual aspects, for example the component characteristics, also impacts the space efficiency.

❸ **Picking efficiency:** Refers to time efficiency during the picking tour, which is the amount of time spent on performing picking activities compared to the total time spent during the picking tour. Several design variables, for example the storage assignment policy, the picking information system and the picking package design are highly relevant for the picking efficiency.

❹ **Setup efficiency:** Refers to the time spent in between picking tours and include activities such as the printing of lists, configuration of the information system or retrieval of the picking package carrier etc.

❺ **Balancing efficiency:** Refers to the amount of waiting time that occurs between picking tours due to system losses and inability to equalise the cycle times of preparation and assembly. The work organisation is a key decision in the materials preparation design for balancing efficiency.

❻ **Transport efficiency:** Refers to the transport requirements both for replenishing materials at the preparation area as well for delivering prepared materials to the assembly process.

These six aspects of efficiency represents the resource requirements of materials preparation. In Chapter 4, the various efficiencies discussed here are related to the various design options of the materials preparation design variables.

2.4. Ergonomics

The ergonomic impact of the design decisions refers to considering how the preparation can be performed safely and efficiently. In this handbook, ergonomics is considered from the perspective of work environment, with the addition of aspects related to the psychosocial milieu. The approach taken for deriving the ergonomics framework presented in this chapter has been to review various ergonomic standards[7] used at the companies associated with the research project. From this review, the important ergonomic factors are listed as follows:

”Ergonomics is an approach to job design that focuses on the interactions between the human operator and such traditional environmental elements as atmospheric contaminants, heat, light, sound, and all tools and equipment[6]”

❶ Musculoskeletal load
❷ Noise
❸ Illumination/visual conditions
❹ Climate/temperature
❺ Air pollutants
❻ Vibrations
❼ Effect on skin
❽ Work injury risks
❾ Psychosocial environment

These factors correspond with the VASA standard used at Volvo, with the addition of the ninth factor psychosocial milieu here treated as summary term for many similar elements found across the multiple standards reviewed. Factor 1 – musculoskeletal load – is of most concern in this handbook, as manual labour is a central premise. Each term is treated in the subsequent subsections in terms of how they can be assessed and how they relate to materials preparation design.

5) Hanson, R. and Finnsgård, C., (2014). ”Impact of unit load size on in-plant materials supply efficiency”, International Journal of Production Economics, Vol. 147, pp. 46-52.
6) Definition from APICS dictionary.
7) The standards which most of the terminology and frameworks presented in the chapter originate from are VASA and RAMPII.

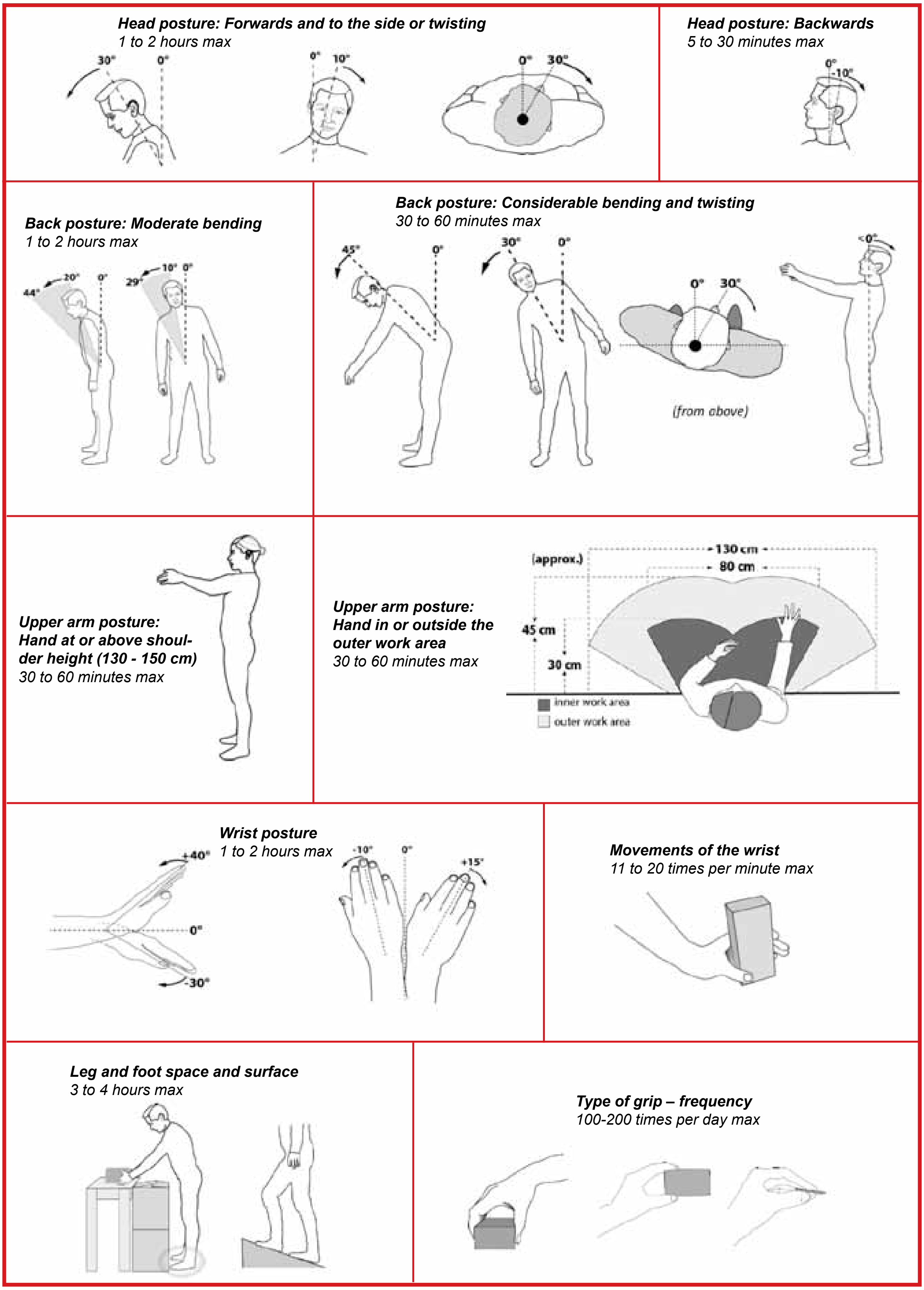

Figure 2.1: Examples of postures and limits (max) for ensuring a sound ergonomic work conditions[8].

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8) Material adopted from the RAMP II framework.

2.4.1. Musculoskeletal load

The musculoskeletal load is assessed by the frequency, duration and weight of the work tasks and any lifts that have to be made in the preparation.

In order to exemplify how the musculoskeletal load can be assessed in materials preparation, the RAMP II framework is highlighted as one example of a tool for ergonomic assessment of manual work tasks that adheres to European and Swedish work environment standards and legislation. The reader should however note that many similar frameworks exist, often adapted to fit the situations encountered in the own company specific setting.

The RAMP II framework consists of three parts:

1. The frequency and duration of different **postures**
2. The weight handled during, and the frequency of, **lifts**, and
3. The frequency and force limitations for **push/pull** activities

2.4.1.1. Postures

In Figure 2.1, the main postures and their recommended limits during a full shift of work (8 hours) in the RAMP II framework (Risk Assessment and Management tool for manual handling Proactively) for ergonomic assessment are shown.

The postures that result from performing the materials preparation work depends to on the design of the materials handling equipment, the picking package and on the choice of storage packaging. In materials preparation, the (tentative) links, between the strenuous postures in Figure 2.1 and the materials preparation design are shown in Table 2.4.

RAMP – Risk Assessment and Management tool for manual handling Proactively

2.4.1.2. Lifts

Lifts may occur in materials preparation either when components are picked or when the picking package is moved. The risk related to the physical wellbeing can be assessed by considering the weight being lifted and the frequency with which the lifts are made.

- **Weight:** depends on the weight of the component variant being picked and how many components are picked at once or, if an entire package is lifted at once, the unit load quantity.

- **Frequency:** refers to how often the lift occur, which is determined by the number of pick activities per time unit. Generally, the faster the picks can be performed, the less weight should be picked.

To exemplify the impact of the frequency on how much weight can be lifted without putting the physical wellbeing of the picker at risk, the RAMP II classification for frequency and weight of lifts (performed with two hands, close to the body, no twisting) is shown in Table 2.5.

The guideline in RAMP II for a “risk-free” lift is a value lower than 3 in Table 2.5, while values between 3 and 4.9 pose some risk for the operator and values at or above 5 pose a major risk.

Table 2.4: Links between the RAMP II strenuous postures in manual work and the design areas.

Posture	Linked design areas	Sections in the handbook
Head: Forwards, to the side or twisting Backwards	Picking information system (type) Storage packaging (type) Materials exposure (tilted packaging) Materials handling equipment (shelf-height)	4.6, 4.8 and 4.9
Back: Moderate bending Considerable bending and twisting	Storage packaging (pallets) Picking package design Layout and movement pattern	4.5, 4.6 and 4.7
Upper arm: Hand at or above shoulders (130-150 cm) Hand in or outside the outer work area	Materials exposure (tilted packaging) Materials handling equipment (shelf-height)	4.6 and 4.8
Wrist: Posture and movements of the wrist Type of grip - frequency	Component characteristics Materials exposure	3.1 and 4.6
Leg and foot space and surface	Not related to any particular design area	-

Table 2.5: Classification of frequency and weight of lifts, based on the RAMP II framework for ergonomic assessment. The light grey and dark grey areas indicate the zones in which lift supports should be considered.

	Number of lifts per day	≤ 12	13 - 24	25 - 60	61 - 96	97 - 240	241 - 480	481 - 960	961-1920	1921-2880	2881-3840	3841-4800
	Equals number of lifts per hour	≤ 1.5	1.6 - 3	3.1 - 7.5	7.6 - 12	13 - 30	31 - 60	61 - 120	121 - 240	241 - 360	361 - 480	481 - 600
Weight	over 25 kg - 30 kg	6.5	6.5	7.0	7.6	8.0	8.6	9.9	14.3	23.9	35.9	49.7
	over 20 kg - 25 kg	5.4	5.4	5.8	6.3	6.6	7.1	8.3	12.0	19.9	29.9	41.4
	over 15 kg - 20 kg	4.3	4.4	4.7	5.1	5.3	5.7	6.6	9.6	15.9	23.9	33.1
	over 10 kg - 15 kg	3.2	3.3	3.5	3.8	4.0	4.3	5.0	7.2	12.0	17.9	24.8
	over 7 kg - 10 kg	2.2	2.2	2.3	2.5	2.7	2.9	3.3	4.8	8.0	12.0	16.6
	over 5 kg - 7 kg	1.5	1.5	1.6	1.8	1.9	2.0	2.3	3.3	5.6	8.4	11.6
	over 3 kg - 5 kg	1.1	1.1	1.2	1.3	1.3	1.4	1.7	2.4	4.0	6.0	8.3
	1 kg - 3 kg	0.6	0.6	0.7	0.8	0.8	0.9	1.0	1.4	2.4	3.6	5.0

If the lift is performed further out from the body, then the factors in Figure 2.2 should be multiplied with the value from Table 2.5. Further considerations for the lifts that are part of the RAMP II framework will not be detailed in this document. Instead, the reader is referred to the RAMP II source material for further details.

The designer can influence the risk of lifts by considering the design of the storage racks, the picking package and carrier, as well as the layout and movement pattern and storage policy. If the components are too heavy for manual lifting, regardless of how the design is chosen, then lifting supports should be considered for the design – see sections 4.4 (page 33), 4.5 (page 35), 4.6 (page 37), 4.7 (page 39) and Design Case 6.4 (page 74).

2.4.1.3. Push/pull

Depending on how the design is chosen, there may be push/pull activities that have to be performed, for example when a moving picking package carrier is used. Table 2.6 shows the RAMP II guidelines for push/pull activities, in terms of the force required to start the motion of the object (left part of Table 2.6) and the force required to keep the object in motion (right part of Table 2.6).

The guidelines for push/pull can be applied when a moving picking package carrier is used, but also when for decision of whether to use manual or electric pallet sliders (see Design Case 5, page 75). If the force requirements are exceeded for a fully loaded picking package carrier, but there is a benefit to use a moving carrier instead of a stationary design, then semi-automatic or automatic solutions can be considered (see section 4.7, page 39).

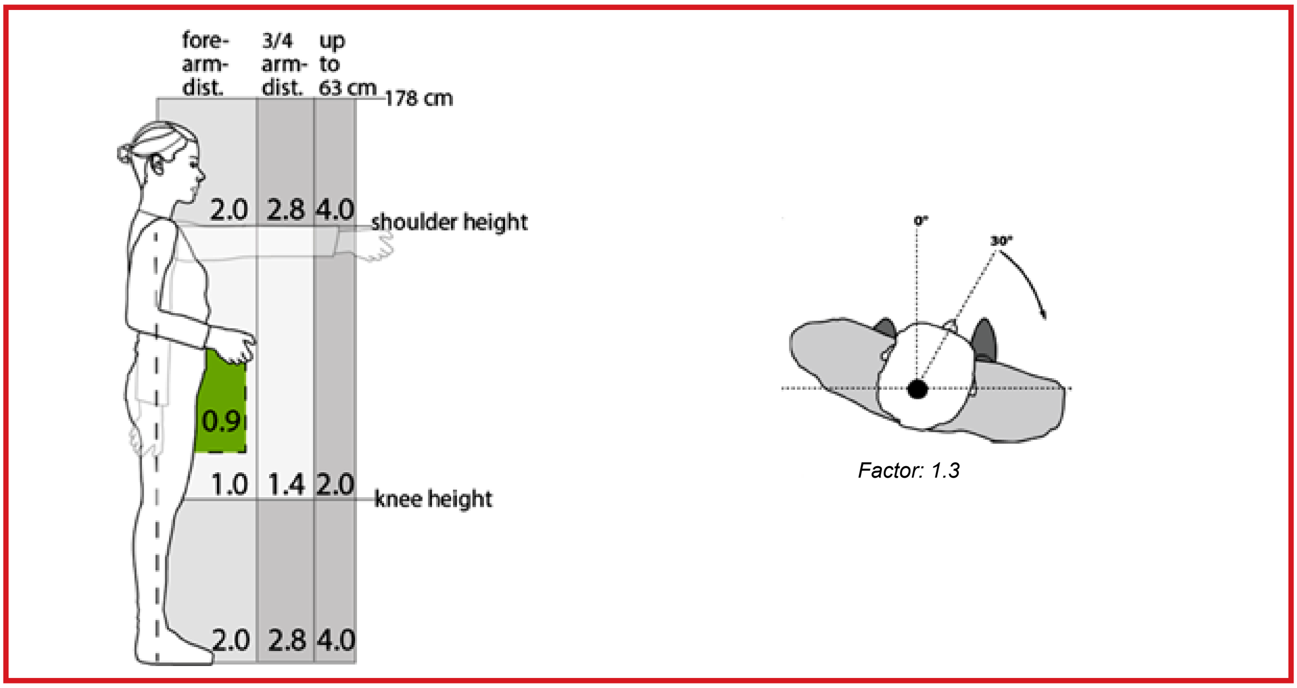

Figure 2.2: Factors for arm extension and torso twisting during lifts, which complement the factor values in Table 2.5.

Table 2.6. Classification of push/pull activities by frequency and force (left table: starting force; right table: continuous force). The light grey areas indicate the zone where alternatives to fully manual handling should start being considered.

Starting force for push/pull

Force value	Times per day	≤ 1	2 - 16	17 - 96	97 - 240	241-480	481-1920
	Times per hour		≤ 2	2.1 - 12	13 - 30	31 - 60	61 - 240
	501 - 600 N	8.5	10	10.5	14	14.5	24
	451 - 500 N	7.5	9	9.5	12.5	13	22
	401 - 450 N	6.5	8	8.5	11	11.5	20
	351 - 400 N	6	7	7.5	9.5	10	18
	301 - 350 N	5	6	6,5	8	8,5	16
	251 - 300 N	4	5	5	5	7	14
	201 - 250 N	3	4	4	4	5	12
	151 - 200 N	2.5	2.5	3	3	4	5
	101 - 150 N	2	2	2.5	2.5	3	4
	51 - 100 N	1.5	1.5	2	2	2.5	2.5

Continuous force for push/pull

Up to 8 meters: Use the force values in the table.
9 -30 meters: Add 50 N to the measured force to calculate the force value.
31-60 meters: Add 100 N to the measured force to calculate the force value.

Force value	Times per day	≤ 1	2 - 16	17 - 96	97 - 240	241-480	481-1920
	Times per hour	hour	≤ 2	2.1 - 12	13 - 30	31 - 60	61 - 240
	501 - 600 N	10.5	12	12.5	17	19	30
	451 - 500 N	9.5	11	11.5	15.5	17.5	28
	401 - 450 N	8.5	10	10.5	14	16	26
	351 - 400 N	7.5	9	9.5	12.5	14.5	24
	301 - 350 N	6.5	8	8.5	11	13	22
	251 - 300 N	6	7	7.5	9.5	11.5	20
	201 - 250 N	5	6	6.5	8	10	18
	151 - 200 N	4	5	5	5	8.5	16
	101 - 150 N	3	4	4	4	5	14
	51 - 100 N	2.5	2.5	2.5	3	4	12

2.4.2. Other factors in the work environment

Aside from the weight, load and frequency of work tasks and lifts, environmental factors in the facility is also important for the materials preparation designer to consider, although many of them may be part of the context. A list of environmental factors and indications on recommended limits that have been identified in ergonomic guidelines used at the companies within the research project are shown below. The reader is referred to the VASA standard used at Volvo for further details.

2.4.3. Psychosocial environment

For promoting a sound psychosocial environment, the following three questions regarding the job design should be considered:

- Can the operator influence job design?
- Can the operator influence the work pace?
- Is the work performed in bursts to catch up or to create longer breaks?

For an ideal work task design, the operator should be able to influence the job design and work pace, and the work pace should be stable rather than performed in bursts. The base requirement of how the job is designed and how the pace is set is, however, always that the materials preparation work can be completed in takt with the assembly process. Further, solutions that smoothen the work pace over the shift should be considered, for example by making the picking information available at a set pace, which may be more or less feasible with various information systems (see section 4.9, page 42).

Table 2.7: Examples of recommended levels for environmental factors in the work environment, from the VASA standard and company guidelines within the research project.

Ergonomic factor	Recommended level (RAMP II)
Noise level	< 78dB Noise level should allow for normal conversation at 2 metres distance
Visual conditions/ illumination	> 700lux (at floor level)
Climate/temperature	20-22ºC (light work) 18-21ºC (moderate work)
Air pollutants	< 20% of hygienic limit for a specific substance Lowest possible level, given technical possibilities
Vibrations	8h; < 2,5 m/s2 (hand/arm) < 0,5 m/s2 (whole body)
Effects on skin	Not likely applicable to MP (see VASA-standard for details)

2.4.4. Design variables and factors in the context that are relevant for ergonomics

The context factors and design variables listed in Table 2.8 should be taken into consideration when evaluating the design from an ergonomics perspective.

Table 2.8: The context factors and design variables that influence the ergonomics and in which section they can be studied further in the handbook.

Variables	Section in handbook
Context	
Demand characteristics	3.1 (page 23)
Component characteristics (weight, shape)	3.2 (page 24)
Design	
Weight of movable picking package carrier (push/pull activity)	4.7 (page 39)
Picking and placing heights (height of shelves, height of pallets, height of picking package)	4.6 (page 37) and 4.7 (page 39)
Materials exposure (tilted packaging, pallet sliders for long side access)	4.8 (page 40)
Use of lift supports for heavy parts	4.8 (page 40)
Information medium	4.9 (page 42)
Storage packaging	4.6 (page 37)

2.5. Cost

Aside from the direct benefits to the system from high levels of quality, productivity, flexibility and ergonomics, high levels with regard to these performance objectives likely lowers the overall cost associated with materials preparation. High levels of quality mean few errors during preparation and hence low costs for rectifying errors. High flexibility means that changes that needs to be made to the process costs less to carry out. A higher productivity directly reduces costs associated with man-hours, floor space and inventory, and good ergonomics is typically associated with higher productivity.

"Each of the various performance objectives have several internal effects, but all of them affect cost[9]"

Aside from the operating costs, there is also the investment cost, which has to be accounted for when choosing between different design options. The investment cost refers to the costs of equipment or for implementing a specific design option. This handbook does not cover cost estimation models for various design options, but will highlight some effects on the investment cost from choosing various design options.

9) Slack, N., Chambers, S. and Johnston, R. (2010). "Operations Management", 6th ed., Pearsone ed. ltd, England: Harlow

Summary of chapter 2
Materials Preparation Performance

This chapter has discussed materials preparation performance. Five performance objectives were explored and ways of measuring the performance were suggested.

The chapter first dealt with materials preparation quality – the degree by which the prepared materials conform to the requirements of the customer process. For quality, both basic requirements and performance requirements must be fulfilled. Basic requirements ensure correspondence of the prepared materials corresponds with the assembly schedule and the Bill of Materials (BoM), and performance requirements refer to additional criteria, for example positioning, which, when applied, improves the support provided to the customer process. Three important quality measures were discussed – the picking accuracy, the quality adjustment cost, and the preparation error response time. The picking accuracy reflects the amount of preparation errors, and various types of errors were presented along with typical solutions for how to rectify them (see Table 2.1). The quality adjustment cost refers to the cost of rectifying errors and depends on the type of error and on what solution is applied. Finally, the preparation error response time is the required time for resolving a preparation error.

Flexibility was discussed, referring to how well change can be handled. Several types of changes happen in the production system which the materials preparation has to be adapted to, including new product introductions, product modifications, mix fluctuations, volume fluctuations, and changes of the delivery schedule. If the materials preparation process has low flexibility, adaptations will be costly and the ability to reliably supply the customer process will be comprised. Two measurements of flexibility were brought up. Range flexibility is the range of change which can be carried out without a noticeable effect on the performance, measured, for example, as the number of new products which can be introduced. Response flexibility, the second measure, refers to the costs or the lead time required to carry out the adaptations.

The productivity performance objective represents how much resources are spent on the tasks which the materials preparation is designed to accomplish. Six types of efficiencies were presented, which can be applied to assess productivity. Preparation efficiency is the total resource requirements of the preparation and assembly activities, and it is important to reduce this total. Space efficiency refers to the amount of occupied floor space. Picking efficiency refers to the proportion of time spent on picking activities during the picking tour, and is a key measure when evaluating various design alternatives. Setup efficiency refers to the requirements to setup a picking tour, for example administrative tasks. Balancing efficiency reflects system losses due to balancing issues between, for example, the materials preparation and the assembly process. Transport efficiency refers to the efficiency by which materials are replenished to the preparation area, and transported to the assembly process.

Ergonomics was the fourth performance objective, which is critical when most of the work is performed by manual efforts. With ergonomics, the objective is to achieve a process which is safe, and which has efficient motion patterns. The RAMPII framework for evaluating ergonomics was presented, and highlighted various aspects related to the work environment and the psychosocial milieu. Nine aspects were discussed, and the recommended levels from the RAMPII framework were shown, including musculoskeletal load, noise levels, visual conditions, temperature, air pollutants, vibrations, effects on skin, work injury risks and the psychosocial environment.

Finally, the cost performance objective was presented, which reflects the investment and the operating costs. The operating costs are a direct consequence of the levels of quality, flexibility, productivity and ergonomics, why a balanced design with improved levels of the other four performance objectives will lead to low operating costs, and thereby improvements with respect to the cost objective.

3. Materials Preparation Context Factors

The materials preparation context includes all factors that are beyond the control of the materials preparation designer. Factors in the context act as prerequisites for the design decisions. These prerequisites have an impact on the performance, either directly or via interaction with the design variables.

The context may also restrict the materials preparation design, and some design options may be suitable whole others not, and some design options may even impossible to implement given a certain context. While the list of context factors that potentially could influence the materials preparation performance is practically limitless, this chapter presents the context factors that have been identified during the research project as the most important for materials preparation design.

The number of context factors that could influence the materials preparation performance is practically limitless. Examples of context factors related to productivity[10] include:

- **Amount of part numbers in kit preparation area**
- **Demand on positioning of components in kit packaging/carrier**
- **Demand on traceability**
- **Extensive packaging handling?**
- **Height of operators**
- **Kit production volumes**
- **Lifting aid required?**
- **Number of parts per kit**
- **Number of picks per hour**
- **Part "pickability": ease of grasp and handling**
- **Part commonality (within kit or batch)**
- **Part sensitivity**
- **Part size**
- **Part weight**
- **Standard kits or not**
- **Type of product**

Similar lists can be prepared for the other performance objectives and there are a myriad of context factors to consider. This handbook focus on six context factors that have been found crucial during the research project. The six context factors, each treated in a separate subsection in this chapter, are the following:

Section 3.1: Demand characteristics
Section 3.2: Component characteristics
Section 3.3: Picker's experience level
Section 3.4: Amount of component variants per part family
Section 3.5: Floor space availability
Section 3.6: Shift capacity and time horizon

10) Hanson, R. and Medbo, L. (2016), "Aspects influencing man-hour efficiency of kit preparation for mixed-model assembly", Proceedings of the 6th CIRP Conference on Assembly Technologies and Systems (CATS), Elsevier, Amsterdam, pp. 353–358.

3.1. Demand characteristics

In many assembly systems, the distribution of demand among different component variants has a shape similar to the one depicted in Figure 3.1, where only a few component variants make up most of the total demand (high-runners) and very many component variants make up the rest (medium-, low-, and zero-runners).

The shape of the demand distribution varies depending on what products are produced.

The shape of the demand distribution varies depending on what products are produced. It is common, for example, that the "tail" is longer – i.e. there are more low- and zero-runners – in heavy-duty vehicle industry compared to automobile industry.

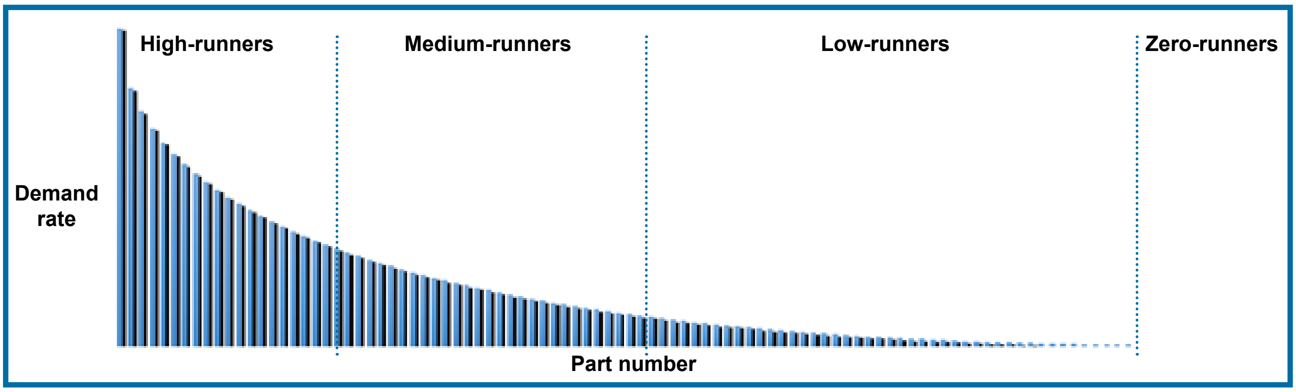

Figure 3.1: Generic parts demand distribution in mixed-model assembly systems. The proportions vary depending on the type of end product, e.g. trucks or heavy duty vehicles usually have a longer "tail" than cars.

The demand for all components managed in the process influences the amount of inventory that needs to be held and the demand for individual part numbers determines how often a component variant is picked and how often a picking location is visited. High-runner component variants have a demand and replenishment must either be made more frequently or in larger quantities to keep up with the demand. Changes in demand for individual component variants also create requirements for mix flexibility.

Depending on the demand characteristics, different design options may be more effective than others. The design areas which depend on the demand characteristics are shown in Table 3.1:

Table 3.1: The design areas for which the demand rate is important.

Design variables	Section in the handbook
Location	4.2 (page 29)
Storage policy	4.4 (page 33)
Storage packaging	4.6 (page 37)
Layout and movement pattern	4.5 (page 35)

3.2. Component characteristics

The component characteristics refers to the distinguishing features of a component or of a component family that in some way impacts the materials preparation performance. Within the scope of this handbook, the following five characteristics are emphasised as particularly important to consider by the materials preparation designer:

❶ **Component size**
(influences the choice of storage packaging, picking package design, policy)
❷ **Component weight**
(influences the need for lift supports, picking height)
❸ **Component shape**
(influences pickability, picking package design)
❹ **Component fragility**
(storage packaging, picking package design, picking policy)
❺ **Component traceability**
(influences picking information)

Figure 3.2: Component size refers to the length (L), height (H) and width (W) of the component.

3.2.1. Component size

The component size refers to the largest dimensions of the component, in terms of length (L), height (H) and width (W), shown in Figure 3.2. The component size sets constraints for the size of the storage packaging that can be chosen (section 4.6, page 37), as well as on the design of picking package (section 4.7, page 39). Larger parts may also not be possible to pick more than one at a time, thereby restricting the picking policy that can be used (section 4.4, page 33). Small parts on the other hand may be beneficial for the time efficiency if multi-picking is used in combination with sort-while place, for example.

3.2.2. Component weight

If the component is heavy, there may be issues with ensuring ergonomic working conditions without using lifting supports at the preparation area. The guideline recommended here – based on typical industrial guidelines – is that all parts or packages above 12 kg (26.46 lb) should be handled with lifting support. See section 2.4 (page 15), about the ergonomics performance objective for more details.

3.2.3. Component shape

Some component types may have a shape that makes them cumbersome to place freely in the picking package, or being very long in comparison with other parts, that may require a more customised solution than the unstructured picking package, for example hooks on which the part can be hung. Further, it is important that the designer accounts for aspects such as some components being difficult to grasp, or to separate from other parts in the storage package, when making the design decisions.

3.2.4. Component fragility

Fragile parts may require protective internal packaging, both in the storage package and in the picking package, to protect the component from scratches or other damages during transport and handling upstream the materials preparation process. Internal packaging handling can have consequences for the picking accuracy if the handling interrupts the picking tour, as well as lowering the time efficiency.

Key resources can be positioned strategically to reduce the impact on performance of internal packaging handling, in terms of, for example, positioning the trash-bins close to regular route between the picking package and the picking locations, or to mount the trash-bin on the piking cart.

3.2.5. Component traceability

Component traceability refers to how various component types can be identified and how simple it is track them throughout the supply chain. Most components have the part numbers represented somewhere on the component, for example etched in the component surface on metal component, included during the moulding process for plastic- or rubber-based components, or written on the component surface. Some components may even be tagged with barcodes or RFID-tags. Component traceability is an important aspect both regarding quality performance and regarding what picking information system that can be applied.

3.3. Picker’s experience and knowledge

Previous research has identified both the picker’s experience level of working with materials preparation and the picker’s knowledge about the product structure to influence the preparation performance, both in terms of productivity and in terms of quality.

Specifically, the picker’s experience and knowledge can either improve performance, by the operator “filling in the blanks”, or inhibit performance, when for example the operator circumvents the system and thus loses out on the quality assurance provided by the picking information system. It is crucial to consider the picker´s experience and knowledge when developing the design, to avoid job designs that are either too complicated, leading to misunderstandings and errors, or too simple, leading to workarounds of the standard. The picker’s experience and knowledge is of course, in turn, dependent on the personnel turnover rate, where it is likely that personnel have less experience and knowledge in systems with higher personnel turnover rates.

3.4. Component variants per component family

Component variants within a component family tend to be more similar in appearance than component variants from different component families. The high degree of similarity typical for component variants in the same component family needs to be accounted in the design, to avoid two variants being mistaken for one another during preparation.

Additionally, with more component variants per component family, the preparation area likely needs to be larger for being able to house all component variants. The number of component variants per component family hence have implications for both the choice of location, storage policy, as well as layout of the preparation area.

3.5. Floor space availability

The amount of floor space available around the materials preparation process will impact the flexibility, in terms of the possibility to extend the storage racks to make room for more picking locations. The amount of floor space available will also set the limits for layout and movement pattern design, as all storage shelves need to be accessible for materials supply to and from the preparation area. The location may be one design option for taking the floor space availability into account, thereby potentially acting as a trade-off decision between an effective layout and the benefits associated with a location close to assembly.

3.6. Shift capacity and order time horizon

The shift capacity refers to the amount of time available for preparation during each working shift (eight hours) and the order time horizon is the amount of time available from when the picking information is available until the prepared materials must be available in assembly. For example, the shift capacity will have implications for flexibility if the materials preparation can be performed during less shifts than actual production, as the spare shift capacity then enables volume flexibility that can absorb increases in production volume.

However, the potential to prepare materials on beforehand is limited by the order time horizon. In some cases, the time horizon may be as short as only three hours and the preparation must be performed during the same shift as assembly.

Summary of chapter 3
Materials Preparation Context Factors

This chapter has dealt with key factors in the materials preparation context. The context refers to those aspects of the production system which cannot be influenced but must be adapted to, and that are in some way relevant for the materials preparation design and performance. With materials preparation design, the context can affect the performance outcome of a given design, and can restrict (or enable) various design options.

While there is an innumerable amount of context factors that potentially can be relevant with respect to materials preparation design and performance, this chapter has focused on six factors which stood out during the research project as being especially important. The factors were the demand characteristics, the component characteristics, the picker´s experience level, the number of components per component family, the floor space availability, and the shift capacity and time horizon.

The demand characteristics refer to how the demand between various component variants is distributed. In most mixed-model assembly contexts, there are relatively few high-runner variants (rarely over 20% of all variants) and a much higher proportion of low-runners, or even zero-runners. Several decisions with respect to the materials preparation design are affected by the demand characteristics, and a proper analysis of the current context should be carried out.

The component characteristics refer to the size, weight, shape, fragility, and traceability of components. The component size can affect how many parts can be picked at once, while the component shape can affect the ease by which components can be placed in the picking package. The component fragility can necessitate that the components are protected with individual packaging, which must be discarded when the component is picked, and can necessitate alternate designs of the picking package. Component traceability refers to the extent by which components can be identified and traced throughout the supply chain, and can be an important prerequisite when choosing what means of quality assurance to apply.

The picker's experience and knowledge refer to how well the picker knows the current process being worked in, and how familiar the components being picked are. Employing more experienced and knowledgeable pickers generally require less support from the process, but can also lead to that critical quality assurance activities are skipped since the activities appear redundant. Knowing who performs the materials preparation is hence crucial when choosing materials preparation design.

The number of components per component family is significant because component variants from the same family tend to be similar looking and are hence easily mistaken for each other. Furthermore, large component families mean that more component variants must be presented at the same preparation area, of which several likely are low-runners. How to handle various component families is therefore an important consideration when materials preparation design is considered.

The floor space availability can determine where the preparation area is feasible to locate within the facility. Furthermore, it can determine the future expansion capabilities when new components must be accommodated in the process. Proper consideration to the floor space availability at an early stage is always preferable, as this is difficult to affect once the materials preparation process has been implemented.

Shift capacity and order time horizon are two important aspects that affect how much time is available to carry out the materials preparation. Sometimes an extra less utilised evening shift can absorb volume fluctuations, but only if the order time horizon – being the amount of time in advance the order information is available – is long enough. Knowing both the shift capacity and the order time horizon can hence make some design options look more feasible, why these are important considerations to include.

4. Design variables

In this chapter, the materials preparation design is presented as nine design variables and each variable has various settings. The chapter discusses how the settings of the nine design variables can be chosen with regard to important factors in the context and how the various options influences the performance. The nine design variables – which have been derived during the research project – discussed here are as follows:

1. **Planning and Control**
2. **Location**
3. **Work organisation**
4. **Policies**
5. **Layout**
6. **Materials handling equipment**
7. **Storage packaging**
8. **Picking package and carrier**
9. **Picking information**

Each section in this chapter deals with one design variable and each variable involves between two and five decisions. The structure of each section is to present the decisions associated with the design variable, one at a time, and explain how the settings influence the performance objectives and relates to the context.

4.1. Planning and Control

The planning and control variable refers to how the production plan is applied for materials preparation (materials planning), how replenishment to the process is triggered (replenishment principle), how quality control is performed (preparation error identification and rectification procedures), and how inventory in the process is monitored (inventory monitoring).

The decisions involved with the planning and control variable can vary between different contexts and can include other aspects not discussed here. The important consideration regarding the planning and control variable is however that the necessary infrastructure around the materials preparation workspace is available and that it enables high performing materials preparation to be possible.

4.1.1. Materials planning

How the production plan is applied is a determinant for which type of materials preparation should be applied and influences what type of components, and how many component variants, are managed by the materials preparation process. The role of the materials preparation designer may include choosing the type of materials preparation to apply and what components to use materials preparation for, and in that case the decisions concerned with the planning and control variable are part of the design. In other situations, the materials preparation designer may be tasked with creating a certain type of materials preparation process for a given set of components, in which case the planning and control variable is part of the context. In either case, how the materials planning is organised is highly context dependent and

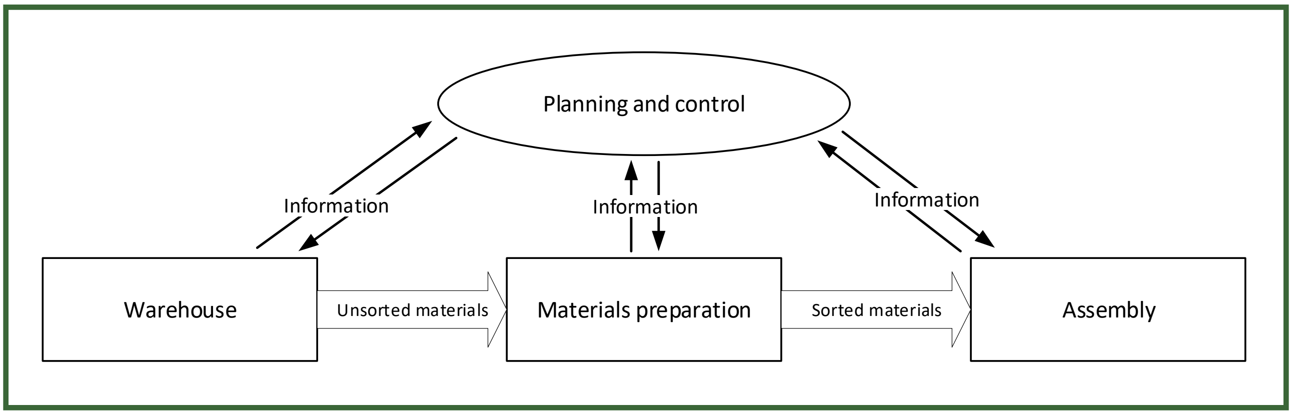

Figure 4.1: Illustration of the role of the planning and control design variable. The variable represents how information is communicated between the materials preparation and the upstream warehouse process and downstream assembly process. This involves materials planning, replenishment principle, and preparation error identification and rectification procedures.

should be designed with consideration to the specific requirements of the context.

4.1.2. Replenishment principle

The way the replenishment to the preparation area is triggered is part of the planning and control design variable. Which replenishment principle to use depends on what storage packaging and materials storage equipment are used, as well as on how the work organisation is designed. Table 4.1 presents three examples of ways to design the replenishment principle. Other principles are also available, but not covered in-depth here, for example Kanban-systems or re-order point systems based on Materials Requirement Planning.

There are many additional ways in which the replenishment principle can be designed. In many of digital picking information systems, there are ways of integrating the replenishment trigger within the system, often utilizing the same technology as the confirmation function. In Table 4.1, the **button press** method could be suitable to use in a pick-by-light system where electric wiring is already in place at the picking locations, while

Table 4.1: Characteristics of three common methods for triggering materials replenishment.

Method	Button press	Barcode scan	Two-bin system
Description	A button, located at the picking location, is pressed to trigger replenishment	Replenishment is triggered by scanning of a specific barcode located at the picking location	Two or more boxes are kept in storage for each part number, where the operator puts empty boxes at a designated output location to signal replenishment
Required technology/ equipment	Electric wiring (or batteries), communication channel to materials supply	Barcode scanner, printed barcode (or barcode on a digital display)	Boxes as storage packaging and flow racks as storage racks
Recommended preconditions	Large picking locations, for example pallets as storage packaging	Labels used at the picking locations; scanning is used to confirm picking activities	None
Influential context/design variables	● Storage packaging ● Storage racks	Picking information system type	● Storage packaging ● Storage racks
Recommended design	● Position button above, to the side of, or otherwise close to, the pick location ● Mount on the storage racks	Integrate barcode in the regular picking location label (together with part no., location identifier etc.)	Locate the output location for empty boxes on the top shelf in the flow rack; attach a flag (or other indicator) that signals that an empty box is at the output location
Performance effects	+ Only small interruption for pressing button + Easily combined with light indicator showing that an order has been made - Can require extensive wiring if many picking locations - Difficult to know when to place new replenishment order	+ Simple if barcode scans are already used for confirmations - Requires barcode scanner - Difficult to know when to place new replenishment order	+ Do not require IT-equipment + Easy to know when to place new replenishment order - May cause some interruptions to ongoing picking tour when empty packaging is handled, or when the last components in an almost empty package are transferred to the new package

the **barcode scan** may be suitable if confirmations are already made by barcode scanning. Similarly, a **pick-by-voice** system may also be configured to include a replenishment trigger, for example by speaking a predefined voice-command. Various replenishment principles are typically combined. For example, **two-bin systems** are often used in combination with **barcode scanning**, where the picker scans the empty bin to trigger replenishment and removal of the empty bin.

4.1.3. Preparation error identification and rectification procedures

If a preparation error occurs, it is crucial that the error is detected and that it can be rectified effectively, in terms of not disrupting the assembly procedure in a detrimental way. When a preparation error is detected in assembly, it is important to have a formal procedure for handling the preparation error that allows for a swift and effective rectification. The rectification procedure should include a way to report the error in order to inform the work with continuously improving the process and to prevent errors from reoccurring. The informing process can be done in conjunction with the daily management sessions at the start of the shift. The points below present a set of observations which have been made throughout the research project regarding preparation error identification and rectification procedures, which can be utilized to inform the design of the preparation process:

- Processes located further away from the assembly process tend to have more complete records over preparation errors. A working hypothesis on why this is the case is that any preparation error that results from processes located further away, as opposed to a process located closer to the assembly process, are viewed as more severe in terms of causing more disruption, why the requirement on reporting the error is enforced to a larger extent. Furthermore, the assembler must report the error for triggering replenishment of the missing component when the materials preparation area is farther away.

- For processes located closer to the line, informal routines for handling preparation errors may develop, where the assembler instead of using the emergency supply function just walks over to preparation area and collects the correct component. When these kinds of informal routines are used regularly, there is no perceived necessity to report preparation errors.

4.1.4. Inventory monitoring

There are various ways of monitoring the inventory in the materials preparation process, which oftentimes can be integrated in the design of the picking information system. For example, in any digital picking information system types which uses confirmations, the confirmations themselves can be used as signals to account for a component being extracted from the storage. It also possible to discount the collected components when the delivery to assembly is performed. If there are high requirements on all inventory accounts being correct, scales could be used in the storage racks.

For situations when formal routines for rectifying preparation errors are not followed, the inventory monitoring may become offset if the assembler visit the preparation area to collect missing components. If these informal routines exist – which is likely if the materials preparation is performed nearby the assembly process – there should be systems in place for registering the extracted components. On this note, it is important to have procedures available at the preparation area for how to update an erroneous inventory level.

4.2. Location

The location refers to where in the production system and supply chain the materials preparation process is located.

The location is a design decision that may have a large impact on the performance, for example in terms of the ability to quickly handle picking errors or in terms of opportunities for work load balancing. The location can also affect how other design variables can be chosen. For example, if the preparation area is located close to the assembly, one option for the operator job role is to have the assembler perform the preparation, which is highly impractical if the preparation is performed in the warehouse. On the other hand, having assemblers performing materials preparation, instead of logistics personnel, may lead to higher salary costs, as assemblers usually have a higher salary than logistics personnel. The location refers to where in the production system and supply chain that the materials preparation workspace is located. For any of the location options dealt with, an effective IT-support system is necessary for managing the preparation, but is here considered as part of the production system and outside the scope of this section. Some aspects of the IT-support system related to the preparation activities are dealt with regarding the picking information system in section 4.9 (page 42). There are four principal locations:

❶ next to the assembly process,
❷ in a separate area between the warehouse and assembly,
❸ in the warehouse,
❹ and in an external facility.

4.2.1. Location next to assembly

Locating the preparation area next to the assembly process simplifies the transport of prepared materials to assembly and allows work task balancing of preparation and assembly tasks. Communication between assembly and materials preparation is also facilitated, as the materials preparation is visible, or at least located very close to, the assembly process.

A location next to assembly reduces the quality adjustment cost, since the correct component can be retrieved directly from the preparation area if an error is detected in assembly. The short distance to the assembly process also simples the transport of prepared materials, where only a short, possibly manual, transport is needed to deliver the prepared materials to assembly.

There may also be opportunities of moving work tasks between preparation and assembly for improving work load balancing when the preparation area is close to the assembly process. Further, if the picker has experience of performing the assembly work, or if the assembler performs the preparation, the number of preparation errors may be reduced as the picker knows what components should be picked and what quality criteria for the various component types are. It can, however, be difficult to find enough floor space close to the assembly process to locate the preparation area there.

4.2.2. Location in a separate area

Locating the preparation area within the production facility but away from assembly, for example somewhere between the warehouse and the assembly process, may be an option if there is insufficient floor space available next to the assembly process for locating the process there.

Having the process located in a separate area does however require a transport between the preparation area and the assembly, likely by vehicle since the distance can be long. Materials must also be transported to the materials preparation area from the warehouse.

If the availability of floor space is high using this option, it may even be possible to use a centralised policy, where several materials preparation processes can be co-located in the same area, allowing for economies of scale. The high availability of floor space normally associated with locating the preparation area in a separate area also brings with high volume flexibility, as it allows the preparation area to be expanded in case the volume increases.

Locating the preparation area separate from both the warehouse and the assembly can be a suitable option if there is a desire to rapidly implement materials preparation, for example if materials preparation has not been used previously in the system or if preparation is tested for new types of component families. The preparation can thereby be introduced in the separate area while enough floor space to locate the process near assembly or in the warehouse is allocated.

4.2.3. Location in the warehouse

Having the process located in the warehouse will simplify replenishment to the process and also allow for a centralised policy to be used effectively, enabling opportunities for economies of scale. The main drawback is the, sometimes, long transport which results and per extension the longer preparation error response time.

4.2.4. Location in an external facility

Locating the process at the supplier or in a separate facility from assembly may be beneficial from a floor space point of view, as floor space within the production facility then is only needed for storing the prepared materials. However, an external transport is likely required in addition to transport within the facility, making the preparation error response time problematic, while also resulting in substantial lead-times.

This option also accounts for locating the materials preparation at the supplier or at a 3PL. In the case of locating the preparation at the supplier or at a 3PL facility it is crucial that the prepared materials received by the production facility holds a high quality level, as spare parts—that are needed in case of preparation errors—may take a long time to make available, thereby putting the assembly at risk.

Another benefit associated with 3PL companies is that they are specialised at handling materials and hence

Table 4.2. Settings and effects of location relative to assembly.
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Option	Effects
Next to assembly	+ job balancing + response time + transport to assembly - replenishment transport - floor space
Separate area	+ volume flexibility + floor space - transport to assembly - replenishment transport
In warehouse	+ work balancing + economy of scale + replenishment transport (+) floor space (-) transport
In external facility	+ floor space + outsourcing (supplier or 3PL) + economy of scale - error response time - transport to assembly

can achieve highly efficient operations, resulting in low preparation costs. Furthermore, many 3PLs are involved with e-commerce and thereby usually operate at high levels of flexibility in regard to changes in the component assortment and volumes, which may be more difficult to achieve in in-house operations.

4.2.5. Performance effects of the location options

Table 4.2 summarises the main performance effects of the different options for the location relative to assembly.

4.3. Work organisation

The design variable which captures the roles of the people involved with the materials preparation process, and how the roles impact the performance, is the work organisation.

The scope of this handbook is materials preparation performed manually the question of "who" performs the preparation work is a central concern. It is not only the role of the picker that is crucial regarding materials preparation performance, but also the roles of those involved with implementing changes in process, for example physical design changes in terms of extending storage racks or rearranging picking locations in the shelves, or changes in the IT-system, i.e. the management and governance. The key decisions that needs to be made regarding the materials preparation work organisation concern **process ownership, job schedule, the picker job role** and **the responsibility for industrial engineering tasks**.

4.3.1. Process ownership

The materials preparation process may be owned and operated by the production department, the logistics department or a third-party organisation. There is a natural, but not necessary, association between the ownership and the location. The three different options for the process ownership decision are discussed here.

4.3.1.1. Production ownership

If production owns the materials preparation, the assembly and preparation occurs within the same organisational unit, which reduces the response time for correcting preparation errors. At the same time, ownership by the production department could limit the extent to which preparation errors are reported, as preparation errors detected in assembly are handled within the department. A production ownership usually allows for job balancing between the preparation and assembly, as various activities, both picking and sub-assembly, and component storages can be moved in between the two.

4.3.1.2. Logistics ownership

With logistics ownership, the preparation is performed as a specialised activity and there may be a opportunities to use standardised design policies, thereby scaling effective designs that develops in the improvement work, and can enable economies of scale where logistics personnel rotate between multiple preparation areas. Process ownership by logistics can create communication barriers with assembly, thus reducing the response time for correcting picking errors. However, the reporting of picking errors may be performed more diligently, as the assemblers can hold the logistics department responsible any detected preparation errors.

4.3.1.3. Third-party ownership

Ownership by a third-party organisation may incur additional communication barriers, but may also provide financial benefits as the preparation cost can be negotiated. Furthermore, third-parties can specialise on materials handling and have economies of scale for achieve highly efficient operations, thereby reducing the preparation cost.

4.3.1.4. Performance effects of process ownership options

The performance related to the different options for the process ownership decision are summarised in Table 4.4.

Table 4.4: Effects from the different process ownership options.
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Setting	Effect
Production ownership	+ communication + job balancing - error reporting
Logistics ownership	+ specialisation + economies of scale + error reporting (-) communication - error response time
Third-party ownership	+ cost of preparation + specialisation - communication

4.3.2. Job design

The work contents for the operator who performs the materials preparation, is determined by job design. There are three principal settings for the job design: **full-time preparation, combined preparation with pre-assembly,** and **combined preparation with assembly.**

4.3.2.1. Full-time preparation

Assigning the operator to full-time preparation implies specialisation of the preparation work, which allows the operator to learn the process in-depth and thereby become highly proficient. Full-time preparation can also enable opportunities for economies of scale where several operators can rotate between multiple preparation areas.

4.3.2.2. Rotation between preparation and assembly

The operator can rotate between performing preparation tasks and performing assembly tasks during the shift. This option would allow the operator to learn how the assembly work is carried out and that knowledge can be helpful for the preparation work. Another benefit is the work task variety – important for ergonomics – that result from performing both preparation and assembly tasks. A disadvantage with this option is the competence level which is required from the operator, who has to know how to perform both preparation and assembly.

4.3.2.3. Combined preparation and pre-assembly or assembly

Combining the preparation with pre-assembly or assembly within the same work cycle can be an effective option if it is difficult to achieve a full balance in the materials preparation processes. Combining preparation with assembly also imply an improved ability move assembly activities between preparation and assembly, thereby improving the balancing capabilities in the system. Combining preparation with pre-assembly or assembly within the same work cycle also increases the operator's knowledge about the product structure, thereby acting in benefit of the quality outcome of the preparation. However, this option requires the preparation to be located nearby the assembly process and finding enough floor space nearby the assembly process can be an issue. This option would also require careful planning by the industrial engineers for balancing the activities effectively.

4.3.2.4. Performance effects of the operator job role

The first order performance effects from the operator job role are summarised in Table 4.6.

Table 4.6: The effects of the operator job role options.
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Setting	Effect
Full-time preparation	+ specialisation and learning + economies of scale - no knowledge of the assembled product
Rotation between preparation and pre-assembly or assembly	+ work task variety - competence requirement
Combined preparation with assembly	+ picking accuracy + work balancing + work task variety - only feasible close to assembly - requires careful planning

4.3.3. Responsibility for industrial engineering tasks

How changes to the materials preparation design are performed, for example addition of new picking locations or updating the picking information upon product introductions, is determined the **responsibility for industrial engineering tasks**.

There are three principal options:

❶ the dedicated support,
❷ the in-house support
❸ and the outsourced support.

4.3.3.1. Dedicated support

Dedicated support means that the manager, or managers, of the process handles the changes as part of their daily responsibilities, possibly together with technicians employed within the company for specialised tasks. This option results in a shorter lead-time for making the changes, especially if the necessary equipment is in stock, as well as a low cost, as the changes then are part of the manager's job description. However, the option requires that the managers have the necessary competencies and certifications (e.g. electric licenses) to perform the changes.

4.3.3.2. In-house support

In-house support means that an organisational unit, or another firm, that is stationed in the production facility, that has a centralised responsibility for industrial engineering tasks, carries out the changes. This type of organisational unit may perform jobs not only related to materials preparation, but also related to, for example, the assembly process. This option may yield a lower cost than a dedicated management approach due to economies of scale, however at the expense of lead time as the organisational may be busy when changes are requested on short notice.

4.3.3.3. Outsourced support

A third option is to use outsourced support, where a third-party, not stationed at the production facility, performs changes upon request. This option may be necessary for some aspects of the materials preparation design, for example the picking information system, but generally leads to both a higher cost and a longer lead-time than the two other options.

4.3.3.4. Performance effects responsibility for industrial engineering tasks

Table 4.7 summarises the performance effects from the different options regarding responsibility for industrial engineering tasks.

Table 4.7: The effects of the responsibility for industrial engineering tasks
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Setting	Effect
Dedicated support	+ lead-time (+) cost (part of daily work) - competence requirements
In-house support	+ cost (-) lead time
External management	- cost - lead time

4.4. Policies

The policies determine where various components are stored (storage assignment policy), how many orders are handled in each picking tour (batching policy), and how items are extracted from storage (picking policy).

There are three important policies in the materials preparation design.
❶ **The storage assignment policy** refers to the logic by which the different component variants managed by the materials preparation process are stored in the storage racks.
❷ **The batching policy** refers to how many orders are completed during the same picking tour, which strongly influences the settings for the picking policy, referring to the sequence in which components are retrieved from the picking locations.
❸ **The zoning policy** is an additional design option that may be used, referring to completion of the picking package over multiple zones and each zone corresponds to one operator.
However, the focus of this report is on single-zone workspaces for materials preparation and further options for the zoning policy is not included. Depending on what storage assignment policy is applied, different levels of flexibility efficiency results. The batching and picking policies impacts the quality outcome of the preparation, while also determining efficiency. For decision concerning any of the three policies, it is crucial that the decisions fulfil the requirements of the assembly process.

4.4.1. Storage assignment policy

There are three principal types of storage policy that may be used:
❶ the random storage policy
❷ the class-based storage policy
❸ the dedicated storage policy

4.4.1.1. Random storage policy

The random storage policy means that the part numbers managed in the process have no fixed picking location, and that the materials supply replenishes materials to nearest free location in the shelves. A random storage policy is less common in materials preparation processes as it does not exploit the product structure. It may however hold some benefit regarding the quality outcome, where the picking locations are continuously changed, thereby preventing the operator from learning patterns in the preparation work that does not necessarily reflect the product structure and the assembly schedule. However, the random storage policy makes no attempt to improve the time-efficiency, but leaves it entirely up to chance to determine – i.e. no differentiation between high runners and low runners. The new product, mix and volume flexibility can be high using this option, as new component variants can be introduced without much planning and already present component variants need not be arranged upon demand changes.

4.4.1.2. Class-based storage policy

The class-based storage policy is often more beneficial for time efficiency than a random storage policy, where the picking locations for high runner component variants can be chosen so that the average travel distance during picking is minimised. Exactly where to store the high-runners and low-runners, respectively, depends om whether a moving or a stationary picking package carrier is used, whether the type of preparation is kit preparation or part sequencing, and what types of storage packaging are applied.

- If the picking package carrier is stationary, the high-runner variants can be stored closest to the picking package carrier to minimise the travel distance. If a moving picking package is used, the class-based policy can be applied in a vertical fashion, where high runner parts are stored at optimal picking height.
- With kit preparation, the number of component variants per part family are likely fewer than if part sequencing is applied, hence the benefits in organising the picking locations for optimal time efficiency may be less. If a structured picking package – a kit-container with an inside structure – there may be further restrictions for organising the picking locations for efficient picking. However, organising the high-runners at optimal picking height is still a viable design option in any of these situations. There may also be restrictions on the sequence in which component variants can in case part sequencing is used, that can prevent the class-based policy to fully used for efficient picking.
- When some of the part numbers in the process are stored in pallets, there may be less flexibility to choose where to store the low-runner component variants and a class-based policy may be problematic to implement and maintain fully. If pallets are present, there may be opportunities to use combinations of storage policies, where, for example, boxes are organised in accordance with a class-based principle, while pallets have dedicated picking locations.

It should also be noted that if some component variants are stored at multiple locations – e.g. to increase the available inventory in the process for a high-runner component variant – efficiency losses may occur when the location with optimal location becomes empty.

4.4.1.3. Dedicated storage policy

The dedicated storage policy refers to all part numbers managed in the process being stored at fixed locations. A dedicated policy may be preferable if a moving picking package is used, but may reduce the flexibility of the process to handle changes in production mix and new production introduction or modifications. Using a dedicated storage may also improve the quality outcome over time, as the operator learns where each component variant is stored. However, pattern learning in this manner may at the same compromise the quality in of case low runner components, as the operator can believe a high-runner variant should be picked and fail to notice that a low-runner variant was supposed to be picked. With a dedicated storage policy, it can be beneficial for quality and efficiency performance to group component variants in the same component family together in the storage, provided the component variants are clearly distinguishable from each other (e.g. different colours).

4.4.1.4. Performance effects of the storage policy decision

The performance effects from the choice of storage policy are summarised in Table 4.8. It should be noted random and class-based policies is uncommon to use in materials preparation due to the restrictions that comes with the product structure.

Table 4.8: The first order performance effects of choosing the storage policy
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Setting	Effect
Random	+ flexibility (+) quality (no pattern learning) - time efficiency (stationary picking package)
Class-based	+ time efficiency (moving picking package) + ergonomics (vertical classes) (-) flexibility (stationary picking package)
Dedicated	- flexibility (+) time efficiency

4.4.2. Batching policy

The batching policy has two principal alternatives:
❶ single preparation and
❷ batch preparation.

In general, batch preparation becomes more time efficient in comparison to single preparation the lower the picking density becomes, and a larger batch becomes more efficient than a smaller batch the lower the picking density becomes. There is however a principal difference between single preparation and batch preparation, where single preparation only has a single placement location. The single placement location simplifies quality assurance, as no placement confirmation is necessary. In contrast, batch preparation involves distributing component among multiple containers and placement confirmations are needed to ensure that components are distributed correctly. As single preparation only involves a single container, it is usually a cheaper option than to use batch preparation, which can require large picking package carriers to be designed. However, the costs of single preparation rise if a structured picking package is used, where a package with customised slots for each component type must be created (see section 4.7 for details around the picking package and carrier). The batch size depends both on the total weight of the picking package carrier, as the weight cannot be too heavy so that the carrier cannot be handled ergonomically acceptably, and on the order time horizon. Larger batches are only possible when the order time horizon is long. The first order effects of the two alternatives are summarised in Table 4.9.

Table 4.9: Summary of effects of choosing the batching policy
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Setting	Effect
Single	+ quality + cost - time efficiency (at low picking density)
Batch	- cost + time efficiency (at low picking density)

4.4.3. Picking policy

The **picking policy** refers to how items are retrieved from storage. Usually, the available options regarding the picking policy depends on the component characteristics. Small components that are not particularly fragile may be picked several at once, whereas larger components that are not particularly fragile may be picked one in each hand, while fragile component should only be picked one at a time. Picking multiple components at once, which is common during batch kit preparation, is referred to as **multi-picking**, as opposed to **single-picking**. During batch-picking, the operator may also count the components picked from storage as they are picked, to make sure that the correct amount is picked, referred to as **sort-while-pick**, or the operator may choose to pick as many as possible and then count how many are placed, referred to as **sort-while-place**. Sort-while-place is generally the faster approach, but may also compromise the quality if components picked in excess are returned to the wrong storage package. The performance effects from the different options regarding picking policy are summarised in Table 4.10.

Table 4.10: The effects of the responsibility for industrial engineering tasks
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Setting	Effect
Single-picking	+ quality
Multi-picking, sort-while-pick	(+) time efficiency + quality
Multi-picking, sort-while-place	+ time efficiency

4.5. Layout and movement pattern

The layout and movement pattern concerns the principal organization of the various equipment and the sequence in which different picking locations are visited during the picking tour.

The layout of the preparation area in combination with the picking policy effectively determines the movement pattern, thereby being a determinant for the time efficiency of the preparation. Of importance regarding the movement pattern is also shape of the picking aisle and the positioning of key resources that are necessary for successfully performing the materials preparation work tasks, which can have an impact on the time efficiency and the quality outcome of the preparation. When designing the layout, two aspects are of main concern for the materials preparation designer: the layout principle, in terms of the principal organization of the storage shelves and the movement pattern during the picking tour, and the positioning of key resources, which determines the positions at the preparation area the operator need to visit routinely to access important equipment, within the picking tour and between picking tours.

4.5.1. Layout principle

There principal types of picking aisle layouts:
❶ The I-shape,
❷ U-shape and
❸ II-shape.

Figure 4.2 shows the three principal layouts and their typical floor space requirements. In Figure 4.2, the floor space requirements for 16 part numbers are shown and includes the space required for the shelves, the replenishment aisle (areas with lengthwise lines) and the picking aisle (area with arrows). To be noted, U-shape layout sometimes have a wider picking aisle to make more room to manoeuvre, why the floor space estimate for the U-shape is a minimum estimate. The arrows

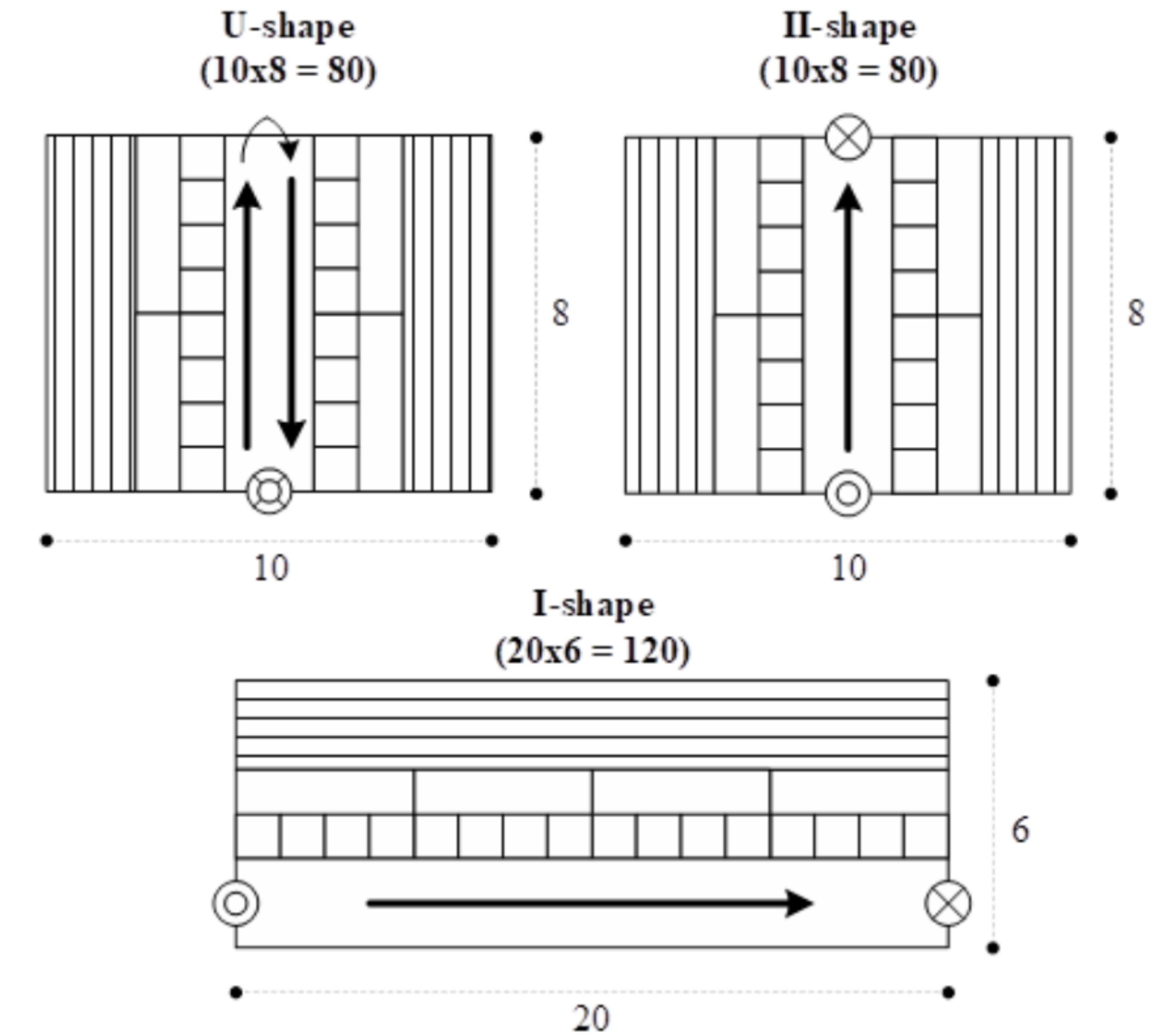

Figure 4.2: Three principal layouts for the materials preparation workspace. The calculations in brackets show the floor space requirements for each of the layouts. The circle with a smaller circle inside represent the picking tour start and the circle with an "X" the end point. Areas with lengthwise lines represent the replenishment aisle. All layouts manage 16 part numbers.

represent the movement pattern when a moving picking package carrier is applied. With a stationary picking package carrier, there is not difference between U-shape and II-shape layouts.

4.5.1.1. I-shape

The I-shape is the traditional layout used alongside the assembly process and may be used for materials preparation when there is a low to medium amount of component variants to manage in a single zone. If numerous component variants are handled, using a I-shaped aisle layout can lead to the travel distance becoming unmanageable, resulting in low efficiency, especially for stationary picking packages. The I-shape layout principle results in a good overview of the preparation area, in addition to creating a predictable and focused work pattern.

4.5.1.2. U-shape

The U-shape is a variant of the I-shape where the operator starts and finishes the picking tour at the same point and may yield even better time efficiency than the I-shape, as the picker starts and ends the picking tour at the same location. Starting and ending the picking tour at the same location also means that the operator can begin the next picking tour as soon as the previous finishes, as there is no need to reposition to reach the starting point of the tour. A drawback with the U-shape is that the materials supply has to have access to all sides of the preparation area, thereby being a costly solution in terms of floor space.

4.5.1.3. II-shape

The II-shape works the same as the I-shape except for picks being made on alternating sides of the picking aisle while the picker moves through the aisle with the picking package carrier. When combined with a moving picking package, the II-shape results in a high time efficiency as the travel distance per picked part becomes very low. As with the U-shape, materials supply needs access to all sides if the II-shaped picking area, which increases the floor space requirements. When several II-shaped workspaces for materials preparation are located next to each other, the floor space efficiency is higher than for I-shaped preparation areas next to each other.

4.5.1.4. Performance effects from layout and movement pattern

The first performance effects from the choice of layout principle are summarised in Table 4.11.

Table 4.11: The first order effect of the choice of layout principle
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Setting	Effect
I-shape	+ floor space + overview - time efficiency - walking distance
U-shape	+ walking distance (+) time efficiency (-) floor space
II-shape	+ walking distance + floor space + time efficiency

4.5.2. Positioning of key resources

The positioning of key resources is an important consideration in the layout design. What the key resources are depends on the context but, for example, if sensitive components are prepared, they are likely stored in some type of internal packaging that needs to be discarded during the picking tour, why a trash bin is needed somewhere at the preparation area. Depending on where the trash-bin is placed, there will be activities associated with discarding the packaging. Two options for positioning the trash-bin which likely are effective include positioning the trash-bin next to a stationary picking package – so that the picker can discard the packing every time the picking package is visited for placing components – or mounted on a moving picking package carrier.

Similarly, if plastic bins are used as storage packaging, that may be the case when materials are delivered directly from the supplier, output lanes for empty boxes needs to be positioned somewhere at the preparation area. Further, the position of stationary picking packages, printers for lists and labels, subassembly worktables and lifting supports needs to be positioned wisely to allow an efficient workflow, causing the least amount of interruptions to the picking tour as possible.

4.6. Storage packaging

Storage packaging refers to packaging type and exposure of materials in the shelves at the preparation area.

The storage packaging design variable may not completely be up to the materials preparation designer to choose freely, as the type of packaging may, for example, be part of a supplier agreement that is difficult to change. In any the case, the storage packaging has implications for the overall design of the preparation area, as well as on the performance objectives in terms of quality, time efficiency and flexibility. The storage packaging design variable is concerned both with the **storage packaging type** and the **materials exposure**, in terms of how the packaging contents are presented to the picker.

4.6.1. Storage packaging type

There are two principal types of storage packaging to choose from:
❶ pallets
❷ and boxes.

With pallets, the are numerous different variants and sizes, ranging from pallets with special properties – for example pallets removable sides and others with internal structures for presenting the contents in an optimal way – in a variety of different materials (plastic, metal, wood etc.) to the standardised EUR-pallet. The most common form of pallet in industry is the EUR-pallet. It is primarily with respect the EUR-pallet the various aspects discussed here applies for. Many different types of boxes exist, many with special properties, and

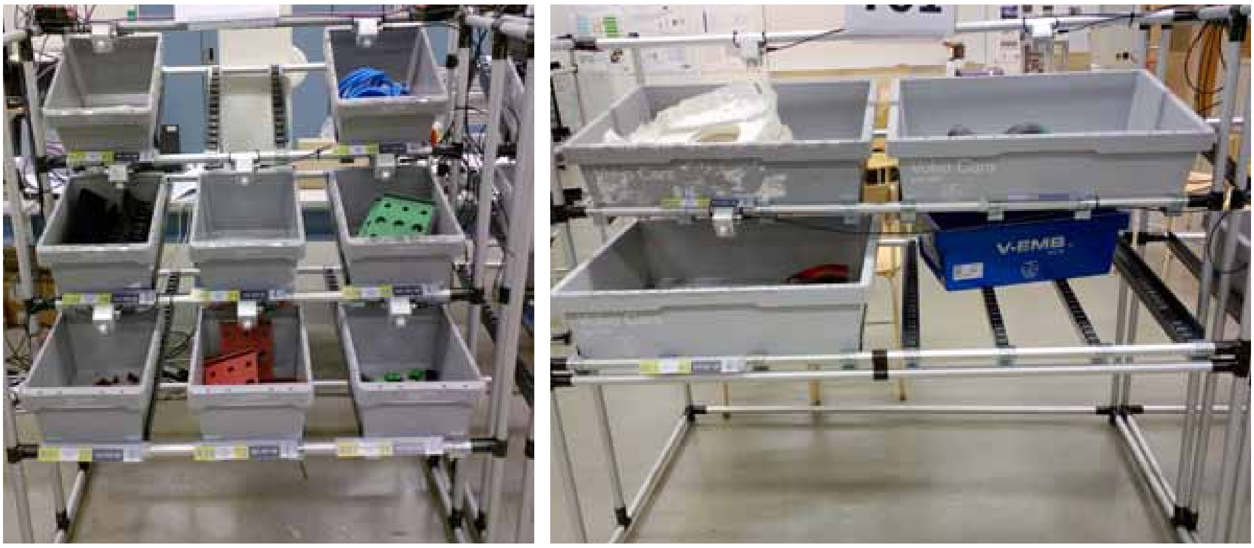

Figure 4.3: Pictures of two box types when stored in flow racks. To the left, smaller boxes with dimensions 200x300x-200mm, and to the right, boxes with dimensions 600x800x200mm.

the same remark also applies for the aspects related to boxes discussed here. The main type of boxes applied in industry is plastic boxes of various sizes, often in size of fractions of the EUR-pallet, which is the box type the aspects presented here applies to.

The discussion here is also primarily focused on aspects related to returnable packaging, as opposed to packaging for one-time uses. Previous studies have shown that application of one-time use packaging often is a cheaper option than to use returnable packaging, as the costs of cleaning and transporting the empty packages likely are higher than the costs of producing new one-time packages. Furthermore, the use of one-time use packaging is – due to the requirements on cleaning and transportation for returnable packaging – likely a better option from an environmental sustainability standpoint, especially for longer-route supply chains. However, most of the aspects discussed here revolves around the effects within the production system, why the various aspects apply for both returnable and one-time use packaging.

4.6.1.1. Pallets

Pallets generally allows for larger unit loads to be presented at the preparation area, thereby extending the time frame between replenishments, but also increasing the amount of inventory held at the preparation area. Using pallets may be beneficial for volume flexibility, where the time frame between replenishments can handle large changes in production volume, but results in low levels of new product flexibility and modification flexibility. However, pallets take up a lot of floor space and adds to the size of the preparation area, thereby increasing walking distances and reducing the time efficiency. Furthermore, it a two-bin replenishment principle is applied for pallets, additional floor space is required for the second pallet, leading to substantial overall floor-space requirements. Pallets are can be stored on shelves but likely not on more than two levels (two-frame pallets), why the preparation are size likely is substantial of pallets is the main type of storage packaging used.

4.6.1.2. Boxes

Boxes on the other hand will make the preparation area more compact, thereby increasing the picking density and the time efficiency, as boxes can be stored on multiple shelf levels. Boxes can also be of many different sizes, thereby adapting the time frame between replenishment for different component variants, depending on the use rate of each component variant, leading to improved flexibility. The time frame between replenishments can also be adjusted by changing the number of boxes being replenished during when each replenishment is made, hence the volume and mix flexibility is a benefit of using boxes. Furthermore, boxes can be stored in flow-racks, which results in improved ergonomics during preparation and during replenishment. A drawback with boxes can be that additional downsizing activities may be necessary, to repack the materials from pallets into boxes, of the supplier agreements are difficult to change, leading to additional material handling costs in the system. The performance effects from the choice of storage packaging are summarised in Table 4.12.

4.6.1.3. Performance effects related to the storage packaging type

The performance effects related to the storage packaging type (pallets or boxes) are presented in Table 4.12.

Table 4.12: Summary of the performance effects from the choice of storage packaging
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Setting	Effect
Pallets	+ volume flexibility - floor space - new product flexibility - modification flexibility - time efficiency - ergonomics
Boxes	+ time efficiency + flexibility + floor space + ergonomics - additional material handling (depends on supplier agreement)

4.6.2. Materials exposure

The materials exposure involves many aspects and extensive research has been carried out on how various aspects impacts picking performance. For aspects related to how the workspace is designed for optimal picking, the reader is referred to Finnsgård and Wänström (2012)[11]. For aspects related to picking from pallets and various ways of improving materials exposure when picking from pallets, for example tilting the pallets, the reader is referred to Hanson et al. (2018)[12].

4.7. Picking package and carrier

The picking package and carrier make up the link between the materials preparation and the assembly process, and the design need to account for how it is applied in the preparation and used in the assembly.

The design of the kit carrier and packaging can have major implications for the workflow and simplicity of the picking scenario, thereby being crucial for both quality, time efficiency and flexibility in the materials preparation. The picking package design refers to how the package in which components are placed are designed. In kit preparation, the picking package is the kit-container. The picking package carrier design refers to the structure that holds the picking package(s). The picking packages may be part of the carrier, where the picking packages are attached to the carrier and delivered as one to the assembly process, or the carrier may be used a tool during the preparation, where the completed picking packages then are delivered by some other means, for example a tugger-train.

4.7.1. Picking package design

There are three principal types of picking package designs: **unstructured, semi-structured** and **structured**.
❶ The unstructured package refers to using a single compartment for all component variants, for example in form a plastic box. An unstructured design may be advantageous in terms of time efficiency, where little

Figure 4.4: An example of a picking package carrier for a batch size of four kits. The kit containers on the carrier consist of boxes of size 300x400x200mm and are unstructured, meaning that all components in the kit share the same compartment. The kit containers are slanted on the trolley to improve the overview from the picker's standpoint.

11) Finnsgård, C. and Wänström, C. (2012). "Factors impacting manual picking on assembly lines: an experiment in the automotive industry", International Journal of Production Research, Vol. 51, No. 6, pp. 1789-1798.
12) Hanson, R., Medbo, L., Assaf, M. and Jukic, P. (2018). "Time efficiency and physical workload in manual picking from large containers", International Journal of Production Research, Vol. 56, No. 3, pp. 1109-1117.

precision is needed for placing the components in the kit. However, when a batch-kit policy is used, the unstructured design provides poor guidance to the picker on how many components are left to pick, thereby being of less support to the picking quality. Fragile components may also not be appropriate with the unstructured kit packaging design.

❷ A semi-structured package design may have different compartments where groups of components should be placed. This improves the quality by providing the operator with some guidance on whether there are components left to pick. Fragile components may also have dedicated slots in the semi-structured package, to protect these from scratches from coming into contact with the other components. The semi-structured picking package may be designed as a "babushka-doll" (the Russian nesting doll building on the principle that inside the doll is another smaller version of that doll, inside which there is a smaller doll, and so on), where several smaller containers are used inside a large container to group components that designated for different assembly workstations.

❸ A structured package design has a specific slot for each component type, thereby requiring more precision during placements but at the same time providing the picker with clear guidelines to ensure that all components are picked. Additionally, the assembler is usually supported to a greater extent from a structured picking package, as it provides guidance for how the assembly work should be carried out. Table 4.14 summarises the first order effects from choosing picking package design.

Table 4.14: The first order effects from the design options for the picking package
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Setting	Effect
Unstructured	**+ picking efficiency** **+ cost** **+ flexibility** **(-) quality** **- fragile components**
Semi-structured	**+ picking efficiency** **+ flexibility** **(+) cost**
Structured	**+ preparation quality** **+ assembly support** **- picking efficiency** **- flexibility** **- cost**

4.7.2. Picking package carrier design

The role of the picking package carrier is to hold the picking packages together while also allowing the picker to fill the packages with components during the picking tour. The picking package carrier design depends on what type of picking package container is used and what batching policy is applied. If batching is used, the design of the carrier will differ substantially whether boxes are used for the picking packages or if compartments in larger rack are applied. It is crucial that picking package carrier is designed with the picking process in mind, so that the compartments, or boxes, are easy to reach and does not impede the picking work, especially if one of the design criteria is to maximise the number of components in each picking package.

There are three principle types of picking package carrier designs:

❶ Stationary, which means that it remains in one place during the picking tour;

❷ Moving, meaning that the operator pushes the carrier during picking;

❸ and Driven, meaning an AGC-type solution.

Which principle type is applied should be decided in conjunction with the decisions on what storage policy and batching policy are to be applied. Design cases 2 and 3 in sections 6.2 (page 72), and 6.3 (page 73), give examples of important considerations regarding the picking package carrier design.

4.8. Materials handling equipment

Materials handling equipment selection involves important decisions for achieving both flexibility and efficiency in materials preparation.

Depending on the context, various type of materials handling equipment may be necessary to have available in the materials preparation process. Here, the primary materials handling equipment dealt with include **the storage rack, lifting supports**, and a discussion around the variety of **tools** that may be necessary to have available in the materials preparation process. It may also be possible for the materials preparation designer to select the transportation method of prepared materials to assembly, which refers to the **prepared materials carrier vehicle**, but this outside the scope of the current and is not discussed further here. Some aspects related to the prepared materials carrier are discussed in design case three in section 6.3.

4.8.1. Storage racks and shelves

The type of storage racks to use depends on the type of storage packaging. Pipe flow-racks are typically used for boxes and shelves are applied for pallets, but boxes may be stored on shelves too. With pipe flow-racks, there are two principal types:

❶ wheel-based and
❷ bolted.

The wheel-based type improves flexibility, where entire sections of picking locations can be added or removed with little effort but can mean a costlier investment than flow-racks without wheels that are bolted to the floor. Pipe flow-racks provides much better options for materials exposure than does shelves, where the flow-lanes can be tilted for exposing the packing contents for the picker and the costs for pallet shelves is usually substantial, as robust structures are required for handling replenishment of often heavy pallets by forklifts. The performance effects from the various types of storage racks are summarised in Table 4.15.

Table 4.15: The first order performance effects from choosing storage racks
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Setting	Effect
Wheel-based pipe flow racks (boxes)	+ flexibility + materials exposure - cost
Bolted pipe flow racks (boxes)	+ materials exposure - cost
Bolted shelves (pallets or boxes)	- flexibility - materials exposure - cost

4.8.2. Lifting supports

The component weight and the picking height determines whether lifting supports are necessary to use during materials preparation. If heavy parts are present in the process, lifting supports may be needed for achieving ergonomic working conditions. The maximum weight limit for manual picking depends on the body posture in which the pick (or placement) is made and can vary between 8 kg when made from chest height and arms are extended and up to 15 kg when the pick is made around hip height and close to the body. The telpher is one approach that provides an easy to manoeuvre lifting support, but at the expense of flexibility in the process, see design case four in section 6.4 (page 74), that exemplifies how a telpher solution can be integrated in the storage rack design. An alternative solution is to use a crane. For heavier components than the maximum limit, lifting supports should always be used.

Figure 4.5: An example from Scania of a telpher-design lifting support. The lifting support shown in the picture has been integrated into the shelves at the preparation area.

4.8.3. Other equipment and tools

Depending on the context, there may be different tools necessary to use during the materials preparation work, for example for opening different types of packaging (cutters, blade-knife etc.) or for performing quality controls of materials (e.g. scales for weight control of completed kits). The tools should be easy to access, for example by the picker wearing the necessary tools or locating the close to or on the picking package carrier (see section 4.5.2. (page 37), about positioning of key resources for similar discussions). The vehicle for transporting the picking package carrier is another example of equipment which the materials preparation designer can consider in its implications both on the preparation process and on the assembly process.

4.9. Picking information

The picking information is the interface between the operator and the system, enabling interaction between the two.

The design of the picking information has an impact on both quality, efficiency, flexibility and ergonomics, but the choice of which type of technology to apply is dependent on the context as well as on the settings of the other design variables. The picking information design consists of three aspects:
❶ the information medium,
❷ the confirmation method
❸ and the information structure.

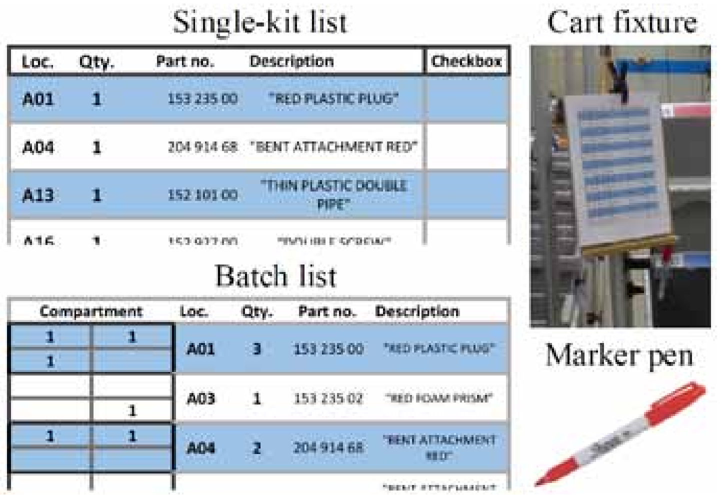

Figure 4.6: Example of a setup with pick-by-list. The picture illustrates a list for single-kit preparation (top left), a list for batch preparation of four kits (bottom left), the fixture holding the list on the trolley (top right), and the marker pen used to check-mark completed order lines (bottom right).

4.9.1. Picking information medium

The picking information refers to the list of components that should be collected to the picking package during the picking tour. There are three primary things that the picking information conveys to the operator:

❶ **what** should be picked
❷ where **from** the pick should be made
❸ the location **to** where the picked component(s) should be placed

The **information medium** refers to the mechanism and technology by which the operator acquires the pick- and placement information. There are five principal types of picking information mediums:

❶ List-based systems, where the pick-list is displayed on for example on paper or on a monitor,

❷ Voice-based systems, where the picking information is received via voice prompts generated from synthesised speech,

❸ Indicator-based systems, where an indicator generated by for example a light or by a laser-projector indicates the location of the next activity,

❹ Mixed-reality-based systems, where a representation of the storage and picking packages allows for spatial guidance on the location for the next activity, and

❺ Augmented-reality-based systems, where real-time computer-generated graphics provides guidance on the location of the next activity.

Each type of information medium can be designed in different ways, by use of different kinds of technology and hardware. Lists can be printed or displayed on a monitor, light indicators can be supplied with electricity

Table 4.17: The first order effects from the design options for the picking information medium
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Setting	Effect
List on paper	+ simple implementation + cost (only paper required) - quality (poor guidance, especially with batching) - flexibility (requires labels at locations)
List on CMD	+ simple implementation + cost (only monitor required) - quality (poor guidance, especially with batching)
Light indicators (cable)	+ picking efficiency (in dense picking areas) - flexibility (wires difficult to move around) - cost
Light indicators (battery)	+ picking efficiency (in dense picking areas) - maintenance (replacing batteries) - cost
Speech prompts	+ quality (-) flexibility (requires labels at locations) - picking efficiency (in dense picking areas)
Mixed-reality	+ picking efficiency (in dense picking areas) (-) cost (comparable cost to pick-by-voice)
Augmented reality	+ picking efficiency - cost (expensive hardware)

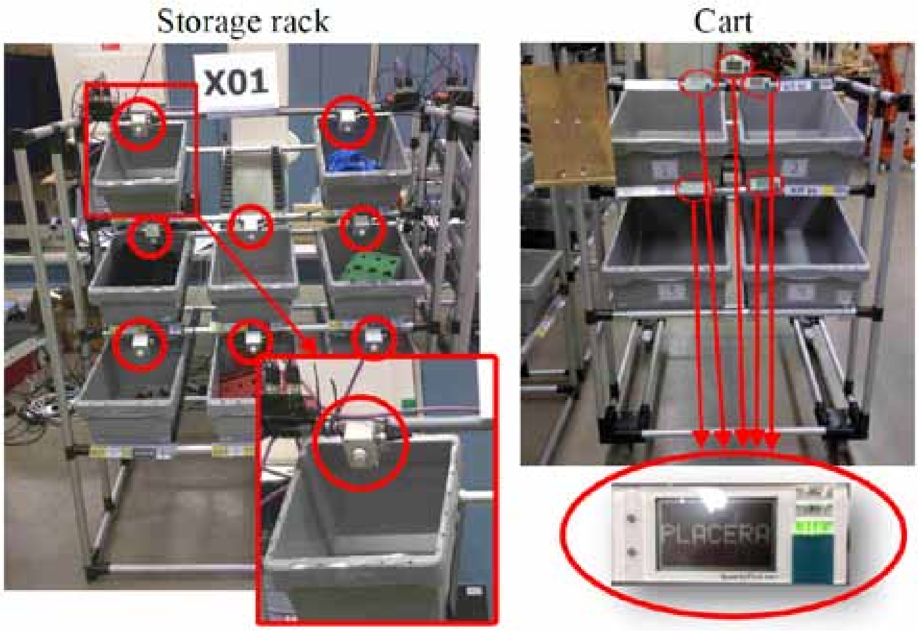

Figure 4.7: Example of a setup with pick-by-light. The picture shows the light indicators on the shelves positioned above each picking location (left picture), and the light indicators on the cart above each kit container (right picture).

by either cables or by batteries, and voice prompts can be generated by a head-set or as part of other wearable devices, e.g. smart-glasses, with integrated speakers. Depending on the type of technology and hardware that is applied, different levels of performance may be expected in the materials preparation process. Table 4.17 shows the first order effects from the choice of information medium.

4.9.2. Confirmation method

The confirmation method refers to how pick- and place activities are reported complete and is used as a means to improve the quality outcome of preparation activities. Confirmation methods are often integrated with a picking information medium but can often be chosen separately. The choice of confirmation method is important for both the quality outcome and the time efficiency, especially with regard to placement confirmations that are necessary with batch preparation. Many of the different confirmation methods can be combined with different information media, where some combinations are more effective than others (see study examples A and B in sections 6.9 (page 79), and 6.10 (page 80), for more details). When selecting confirmation method to use, it is crucial to consider the different situations of confirming when picking components from the shelves and when placing components in the picking packages (in case of bathing being applied).

A common type of confirmation method used in combination with lists – that provides practically no quality assurance – are check-marks with pen. Other more quality promoting options can include handheld-barcode scanners (and button presses, in case a CMD is used to display the list). In pick-by-light systems, button-presses is a common and efficient method for confirming picks, as well as placements in case of batch-kit preparation. Other – more expensive – solutions for light-guided picking include proximity sensors, that generates the confirmation when the operator moves the hand through the sensor field, as well as pins that when touched confirms the activity. Pick-by-voice systems traditionally use voice-prompts to progress to the next pick, but the activities can be further quality assured by use of barcode scanning, at the cost of

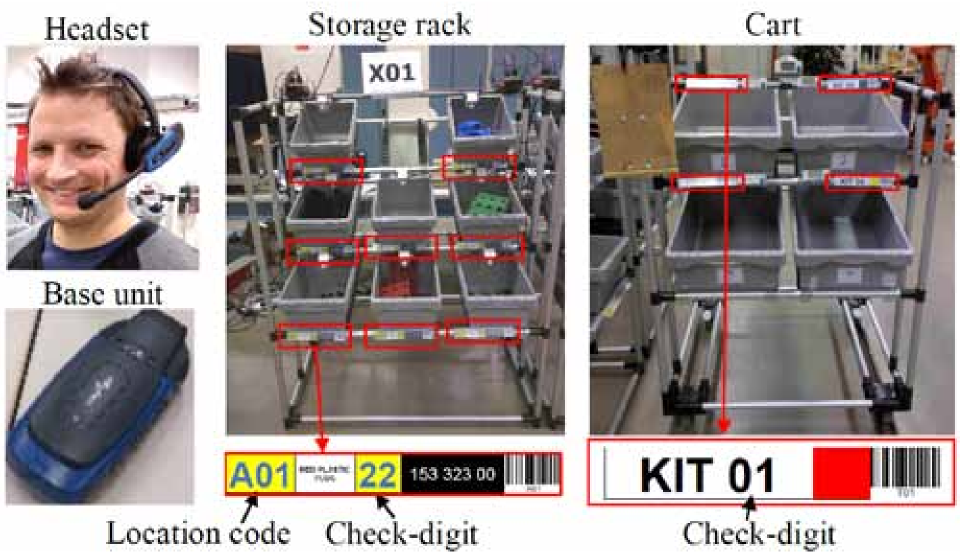

Figure 4.8: Example of a setup with pick-by-voice. The picture shows the headset by which the picker receives and transmits voice dialogue (top left), the base unit (bottom left), the signs with location codes and check-digits at the storage (middle) and at the kit containers on the cart (right).

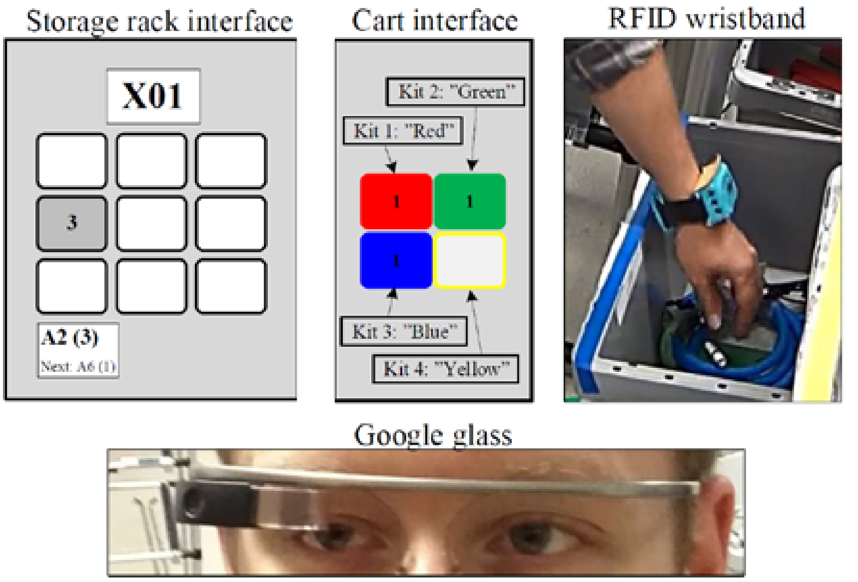

Figure 4.9: Example of a setup with pick-by-vision. The setup consists of a set of smart-glasses (bottom) and an RFID-reading wristband (top right). In the smart-glass screen, the picker sees a model of the shelf (top left) and a model of the kits on the cart (top middle), which indicate what to pick and where to place.

increased time consumption. Vision-based systems, for example mixed- or augmented reality, are still relatively untested but shows great flexibility in terms of confirmation technology, where almost any of the previously mentioned technologies can be used. Fairly recently, various RFID-based applications have emerged for confirmation of picking activities, often involving the picker wearing a glove or a wristband with an integrated RFID-reader that automatically scans an RFID-tag next to the picking location. These RFID-based solutions are still rather expensive, but have shown great potential in both efficiency and quality when applied in preparation. The performance effects associated with the different types of confirmation methods are shown in Table 4.18.

Table 4.18: The first order performance effects from the choice of confirmation method
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Setting	Effect
Pen and check-marks	+ simple implementation + cost - quality
Buttons	+ picking efficiency + quality (-) cost
Sensors	+ picking efficiency + quality - cost
Voice commands	+ quality (-) picking efficiency (in dense picking areas)
Speech prompts	+ quality (-) flexibility (requires labels at locations) - picking efficiency (in dense picking areas)
Barcode scanning	(+) quality - picking efficiency (in dense picking areas)
RFID-scanning	+ picking efficiency + quality - cost

4.9.3. Information structure

The way in which the picking information is formatted and then presented by the information medium is determined by the information structure. For some systems, for example lists or the vision-based systems, there exist numerous ways to structure the information. Here, the various ways of presenting information has been simplified into three main approaches:
❶ text-based,
❷ symbolic
❸ and spatial.

4.9.3.1. Text-based information

Text-based information refers to digits and letters and is a common approach used on lists and in voice-based systems, and can also be generated in smart-glasses. The information presented in text typically includes a location identifier code and the part number. Text-based information is a simple approach that involves generating picking information directly from the planning system, without much need for formatting. However, to be effective, the operator experience level and sense of familiarity with the process must be high, as long strings of digits or similar looking location identifiers can be difficult to learn.

4.9.3.2. Symbolic information

Symbolic information refers to encoded text-based information, where instead of a component variant being expressed as “1001456333” it may instead have name “CAT”, or be represented by a picture of cat. A working hypothesis is that symbolic information is simpler to interpret than text-based information, therefore contributing to shortening the search time, learning times, and therefore improving the picking quality. See design case

Loc.	Qty.	Part no.	Part Name	Checkbox
A01	1	153 235 00	"RED PLASTIC PLUG"	
A04	1	204 914 68	"BENT ATTACHMENT RED"	
A13	1	152 101 00	"THIN PLASTIC DOUBLE PIPE"	
A16	1	152 927 00	"DOUBLE SCREW"	
A18	1	220 557 21	"SMALL GREEN WIRE-BUNDLE	
A21	1	220 567 77	"GREEN ATTACHING CLAMP"	
A29	1	203 745 01	"BLUE ANGLED BRACKET"	
A32	1	216 259 22	"BLUE PLASTIC COVER PLATE"	
A34	1	280 211 89	"RED THIN NOZZLE"	
A45	1	819 156 92	"LIGHT ANGLED BRACKET BLUE"	
B01	1	216 810 33	"RED HOSE"	
B02	1	313 628 28	"LARGE PLASTIC COVER"	
B08	1	507 664 07	"RED LIGHTS LARGE"	
B13	1	213 106 76	"LONG PIPE"	
B15	1	218 223 26	"LARGE BEARING RED/GREEN"	

<table>
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<tr><td>1</td><td>1</td><td rowspan="2">A01</td><td rowspan="2">3</td><td rowspan="2">153 235 00</td><td rowspan="2">"RED PLASTIC PLUG"</td></tr>
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<tr><td></td><td></td><td rowspan="2">A03</td><td rowspan="2">1</td><td rowspan="2">153 235 02</td><td rowspan="2">"RED FOAM PRISM"</td></tr>
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<tr><td>1</td><td>1</td><td rowspan="2">A04</td><td rowspan="2">2</td><td rowspan="2">204 914 68</td><td rowspan="2">"BENT ATTACHMENT RED"</td></tr>
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<tr><td>1</td><td></td><td rowspan="2">A16</td><td rowspan="2">2</td><td rowspan="2">152 927 00</td><td rowspan="2">"DOUBLE SCREW"</td></tr>
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<tr><td>1</td><td></td><td rowspan="2">A18</td><td rowspan="2">2</td><td rowspan="2">220 557 21</td><td rowspan="2">"SMALL GREEN WIRE-BUNDLE</td></tr>
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<tr><td></td><td>1</td><td rowspan="2">A24</td><td rowspan="2">2</td><td rowspan="2">992 482 01</td><td rowspan="2">"GREEN HEXAGON SCREW"</td></tr>
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<tr><td>1</td><td>1</td><td rowspan="2">A29</td><td rowspan="2">4</td><td rowspan="2">203 745 01</td><td rowspan="2">"BLUE ANGLED BRACKET"</td></tr>
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<tr><td>1</td><td></td><td rowspan="2">A32</td><td rowspan="2">3</td><td rowspan="2">216 259 22</td><td rowspan="2">"BLUE PLASTIC COVER PLATE"</td></tr>
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Figure 4.10: Example of two pick-lists. The list on the left is applied with a single kit policy and the picker only needs to see picking location identifier and the quantity. The list on the right is applied with a batch policy, and the picker also needs to see in which kits to place the components (leftmost column).

eight in section 6.8 (page 78), for an example of symbolic information applied in kit preparation.

4.9.3.3. Spatial information

Spatial information refers to picking information presented as a reference to the location in a 2- or 3-dimensional space. Essentially, these types of indicators mark a location relative to something else. The difference between this way of presenting picking information compared to text-based or symbolic information is that the information shows where the location is in the room, thereby removing the need convert one type of information to another. Spatial information is simpler to interpret than either text-based or symbolic, leading to higher levels of quality and efficiency during picking. Examples of information mediums that usually are based on spatial information include light-indicators, mixed-reality and augmented reality.

4.9.3.4. Performance effects from the choice of information structure

Table 4.19 presents the first order performance effects from the different choices of information structure.

Table 4.19: The first order performance effects from the choice of information structure
+ = strong positive influence
(+) = weak positive influence
(-) = weak negative influence
- = strong negative influence

Setting	Effect
Text-based	+ simple to implement + cost - quality (hard to interpret information) - picking efficiency
Symbolic	(+) picking efficiency (+) quality - increased administration
Spatial	+ picking efficiency + quality - cost (requires expensive hardware)

Summary of chapter 4
Design variables

This chapter has presented nine design variables of materials preparation processes that, when combined, creates the materials preparation design. The design variables included planning and control, location, work organisation, policies, layout and movement pattern, storage packaging, picking package and carrier, materials handling equipment, and picking information. Various options of the design variables were discussed, along with the relative performance effects. Moreover, the relevant factors in the context that may influence the choice between the options were also highlighted.

With planning and control, the aspects of materials planning, replenishment principle, preparation error identification and rectification procedures, and inventory monitoring were discussed. Proper choices among these aspects contribute to a design that can coordinate successfully with the larger materials supply system, while also being able effectively detect and correct any errors that may occur in the materials preparation.

The location refers to the choice of physical location of the materials preparation. Four typical design options were discussed: next to assembly, in a separate area, in the warehouse, and in an external facility. While the details are context dependent, the four types discussed provide an overview of the relative effects that can be expected when the location is chosen.

Three aspects were raised with respect to the work organisation. The process ownership can be a prerequisite for communication, job balancing and effectiveness of error reporting. The job role of the picker affects the work contents and can determine the opportunities for specialisation or economies of scale. The responsibility of industrial engineering tasks is a key aspect with respect to flexibility, as it affects the cost and lead time requirements of carrying out changes of the process.

Three important policies were discussed. The storage assignment policy determines at which picking locations various components are stored, and can affect the movement pattern during the picking tour. The batching policy determines how many orders are handled during the same picking tour, and there is usually a trade-off between complicating the work and achieving more efficient picking by batching more orders. The picking policy refers to rules for how components are retrieved from the storage, and single-picking and multi-picking are two important options.

With respect to the layout and movement pattern, the layout principle and the positioning of key resources were discussed. The layout principle is a determinant for the movement pattern during the picking tour and can affect the floor space occupation. The positioning of key resources is crucial for reducing the impact some supporting activities may have, for example discarding of inner packaging or printing of pick lists.

Two aspects related to the storage packaging were discussed. The storage packaging type can substantially impact several performance areas, and the feasible options for other design variables. The materials exposure was not discussed in detail, but valuable research was cited that can show how the materials exposure can be improved by, often, minor alterations at the preparation area.

The picking package and carrier were presented as two aspects which can have substantial effects on the materials preparation performance, depending on what options are applied, and the structure was highlighted as key parameter.

Three aspects were raised with respect to the materials handling equipment. The storage racks and shelves can be important for flexibility, but can also contribute to a better materials exposure at the preparation area. Whether or not lifting supports are required in the materials preparation depends on the component weights, and depending on the context, other types of equipment and tools may also be necessary.

The final variable discussed in the chapter was the picking information. Here, various options of the picking information medium, confirmation method, and the information structure were presented and the relative effects among the options were discussed.

5. A design framework

The aim of this chapter is to provide the reader with a framework that outlines a step-wise process for the design of a materials preparation process, given the prerequisites outline in the introductory chapter in section 1.4.

The framework consists of three parts:

The first part presents a framework for mapping a materials preparation design onto the different options for the design variables.

The second part propose a sequence for the design process - i.e. an order in which the variable values could be set.

Together, the two frameworks provide the materials preparation designer with a short-hand for selecting a viable materials preparation design.

The third and final part presents a discussion about how each design variable may be designed, where important considerations are highlighted. The third part also provides examples from industry on how to design materials preparation processes.

5.1. The design mapping framework

As way to summarise the preceding chapter in terms of the different option available to the materials preparation designer, Figure 5.1 presents the design mapping framework for materials preparation processes. When all values of the design variables have been selected, the framework represents the design of a specific system, in terms of the different settings that may be chosen for the different variables. The idea for the framework stems from Goetschalckx and Ashayeri (1989) and De Koster et al. (2007) and is a specification of a more general framework for the design of order picking systems.

When all values of the design variables have been selected, the framework represents the design of a specific system, in terms of the different settings that may be chosen for the different variables.

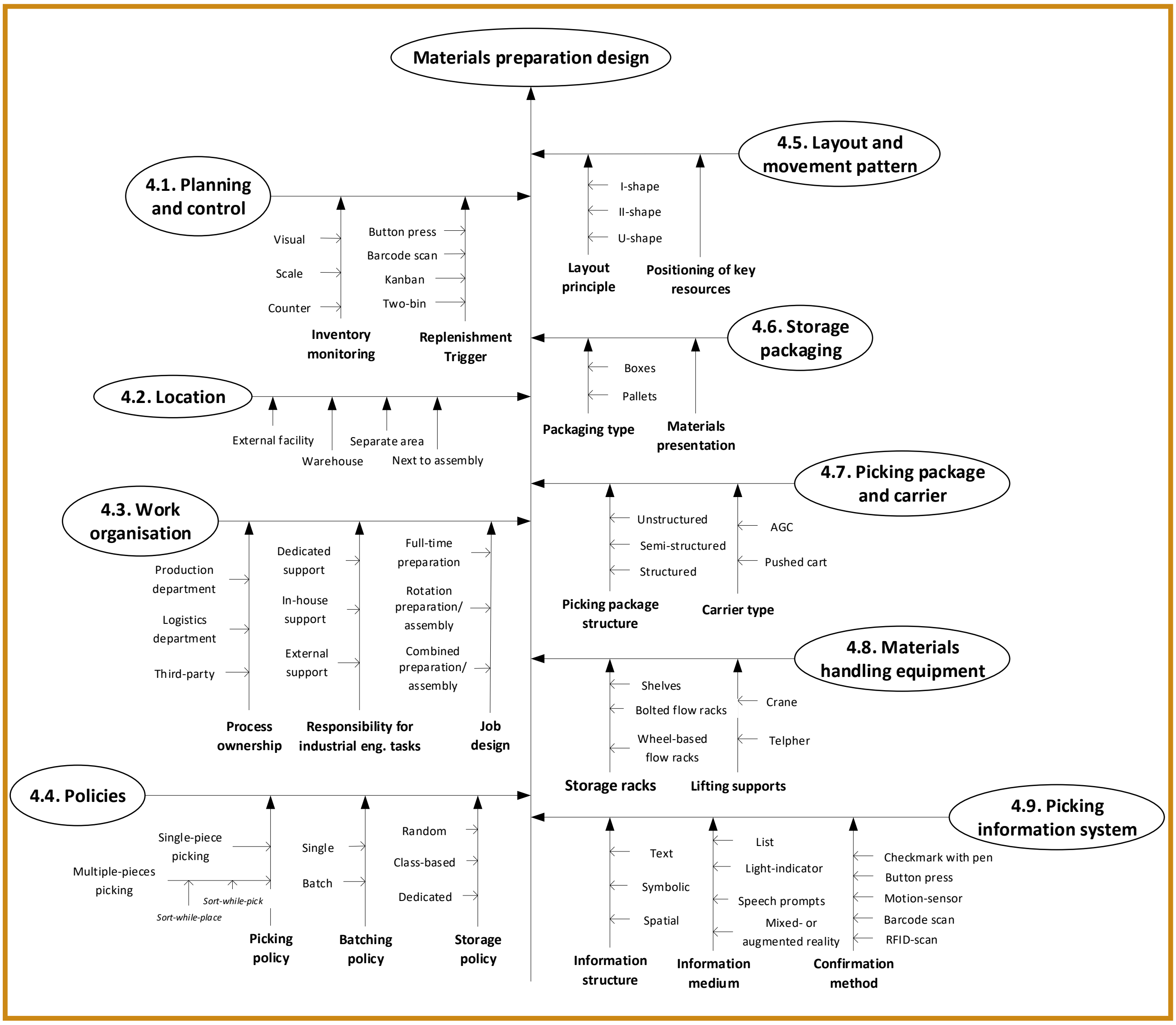

Figure 5.1: The design mapping framework, showing the various settings for the variable in the materials preparation design.

5.2. Design procedure

For navigate among the different design options shown in the design mapping framework in Figure 5.1, the framework in Figure 5.2 suggests an order in which the design variables can be dealt with. The idea behind the framework in Figure 5.2 is that variables in the outer layers function as prerequisites for the variables in the inner layers. Variables within in the same layer must be set with consideration to one another. Outside of the outmost layer is the context. The idea for the framework in Figure 5.2 was first developed by Brynzér (1994) but has been expanded upon in this handbook based on the findings from the research project.

The order in which the variables are set depends on several factors in the context.

The between the design variables shown in Figure 5.2 should be viewed as a suggestion and other ways of the designing the materials preparation process are conceivable. The order in which the variables are set depends on several factors in the context. For instance, if a design policy for materials preparation processes is already in use on company level, then the settings of some of the variables in the inner layers in Figure 5.2 may already be given.

The general idea for the particular order among the variables in Figure 5.2 is that at first, the planning and control, the location, and the work organisation is decided.

The second step entails selecting the policies, in terms of storage-, batching- and picking policy, as well as the layout and movement pattern.

Next, (the third step) the choice of storage packaging, the picking package and carrier, and the materials handling equipment can be made, given the settings of the variables in the outer layers.

The picking information system (step four) is shown in the inner most layer, as the effects from this design choice is highly dependent on the settings of the other design variables.

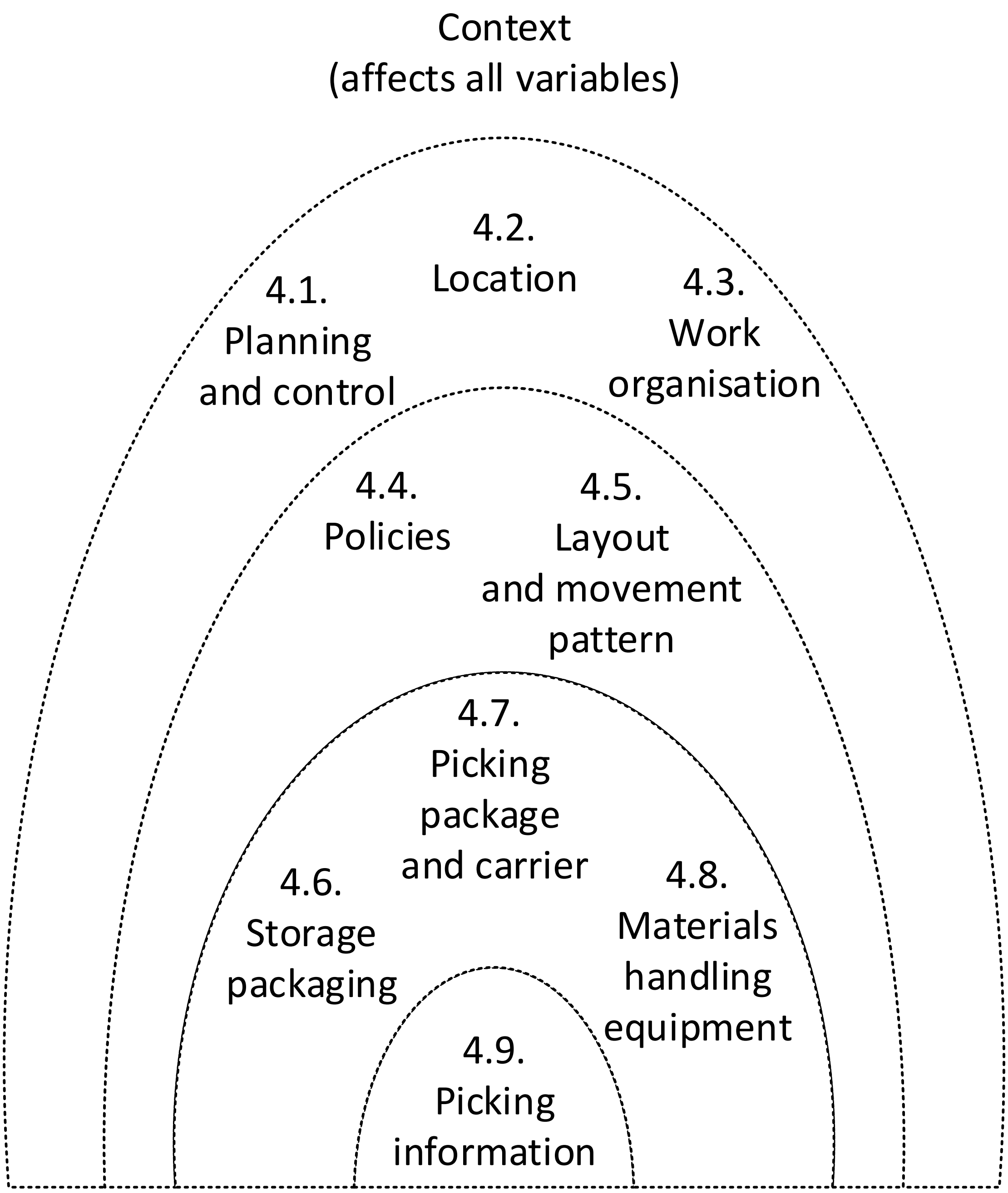

Figure 5.2: A suggested order in which to select the design variables, represented as different layers where the choices of the design variables in an inner layer are affected by the choices made for the design variables in the outer layers, and the context. The figure also shows the corresponding subchapters where the design variables are explained.

5.3. Choice of design

This section present design guidelines for choosing the settings of the design variables. The section is organized in **five subsections**, where each subsection presents rationale for choosing the design variables given a certain desired performance, and are therefore denoted as

❶ **Design for quality** (subsection 5.3.1, page 50),

❷ **Design for flexibility** (subsection 5.3.2, page 55),

❸ **Design for productivity** (subsection 5.3.3, page 58),

❹ **Design for ergonomics** (subsection 5.3.4, page 63) and

❺ **Design for cost** (subsection 5.3.5, page 65), respectively.

It is unlikely that the designer is only concerned with designing the process to achieve a single performance objective with no concern over the performance in regards to the other objectives. The five different perspectives – each perspective corresponding to one performance objective – on how to design the process presented in this section, are therefore all recommended to be reviewed for any considered design, but that priority is given to the most desired objectives.

It is unlikely that the designer is only concerned with designing the process to achieve a single performance objective with no concern over the performance in regards to the other objectives.

Together with the rationale for choosing the design variables given a certain desired performance objective, contextual considerations are also discussed, which may influence or limit the options available for the design variables.

5.3.1. Design for quality

The design objective for achieving a high level regarding quality is to choose a design which minimizes the amount of errors that are made during the preparation, maximizes the possibility to detect errors both at the preparation area and at the assembly process, while minimizing the cost of rectifying any detected errors.

5.3.1.1. Planning and control

Within the planning and control design area, the central design consideration regarding the quality outcome is the "preparation error identification and rectification procedure". The below points show important consideration regarding designing the "preparation error and rectification procedure":

- **Keep a record over identified and rectified preparation errors.** Regardless if the cost of rectifying any one type of error, the error should be reported to alert the materials preparation designer that errors have been observed. The report should contain essential information about the error, for example: part number, order number, error type (see Table 2.1, page 11) and a brief description of how the error was identified and rectified. The report can then be used as basis for finding ways to prevent the errors from reoccurring by modifying the process design.

- **Ensure that the specified rectification procedure is the procedure that is used**. If there are alternative ways available for rectifying preparation errors than the prescribed procedure, find ways to ensure that such informal procedures are not used in place of the prescribed procedures, or find ways to utilise the informal procedures to improve the formal ones so that the formal procedures becomes preferable to use. This is particularly important if the informal procedures require less effort than the prescribed procedures, for example: walking over to the preparation area next to the assembly process to collect the right component, instead of requesting the right component from the emergency supply and wait for the component to arrive. There may also be opportunity for formalizing procedures that develop naturally, in case they show to be more effective at rectifying errors at a lower system cost.

5.3.1.2. Location

For selecting the location of the preparation area, both the **location relative to assembly** and the **centralisation policy** can have an impact on the quality outcome. The points made below summarise the recommended design of the location design area regarding quality:

- The location relative to assembly is important regarding the cost of rectifying preparation errors, as the further away from assembly the location is, the longer the distance will be for emergency supply runs of complementary components. The option closest to the assembly process is therefore the recommended option – **next-to-assembly**.

- The location relative to assembly controls many of the options in the work organisation design area, for example which job role the operator has or which department that the preparation process belong to, which in turn are important for the quality outcome. To enable an integrated job role between preparation and assembly work tasks that improves the picker's knowledge about which are the right components to pick, what the quality requirements for various components are, and to have the process belong to the production department for improving response time to errors detected in assembly, a location **next-to-assembly** is the recommended option.

- A location **next-to-assembly** may also enable the operator to see the end product while performing preparation. The possibility of seeing the end product combined with the knowledge about the product structure gained from also performing assembly tasks (see section 4.3, page 31), for details about the work organisation), may improve the operator's ability to determine whether the right component has been picked, thereby acting in benefit of the quality outcome.

- If a **centralised policy** is used, the ability to maintain and update a common design policy among multiple processes would be improved, where known solutions for certain preventing preparation errors discovered in one process can be implemented in all processes in the area without each process having to invent the solution individually. To have multiple processes following a common design guideline that is continually updated by means of the combined experiences in each individual process can be particularly beneficial in case of new, rather untested, technologies are applied, for example new means of conveying picking information as mixed- or augmented reality. The improvements to the technology made in one process can then be immediately be implemented in the other processes without requiring each process to discover the improvements on their own.

On basis of these arguments, a location next-to-assembly is the preferred choice for the location relative to assembly for high performance regarding the quality objective. However, in regard to the centralisation policy for enabling a common design policy for multiple processes, using a centralised policy together with a location next-to-assembly may not be feasible due to floor-space restrictions close to the assembly process. As a way around this, the management could ensure that known design solutions for preventing preparation errors are transferred to other processes within the system, for example through continuous dialogue between management teams, even though a decentralised policy may be necessary to use.

5.3.1.3. Work organisation

Within the work organization design area, the job role is important for the quality outcome by how it impacts the knowledge and experience of the picker. Further, as was discussed in regard to the location in the previous subsection, the process ownership may impact how preparation errors are rectified and reported. The following points are important in the choice of work organization with respect to quality:

- The operator job design benefits from integrated tasks of preparation and assembly, as with **combined preparation and assembly**. Knowledge about the product structure and about the quality requirements for the components that the operator acquires from performing the assembly work carries over to the preparation work by allowing the picker to assess the components being picked in terms of how they are to be utilized in the assembly process. The improved assessment ability refers both the ability to determine that the correct components are included in the picking packages, and the ability to assess that each included component fulfils the quality requirements and is not defect in some way. To use **combined preparation and assembly** effectively, the location should be next-to-assembly.

- Operators who only perform preparation, as with **full-time preparation**, may accidentally learn patterns between components that are often picked together. This pattern-based knowledge may be used in benefit of the quality outcome when there are fully correlated demands between part numbers, as the components then are always picked together, but may be problematic when the part numbers are not fully correlated, or when the product structure changes upon implementation of new product introductions or modifications.

- The process ownership can impact the way in which preparation errors are rectified, where **production ownership** may result in a shorter response time and a lower rectification cost, as the errors then are handled within the same department as the assembly. However, as have been realized during the research project, the organizational barrier which is created by having the preparation and assembly belonging to different departments, as when the preparation is under a **logistics ownership**, preparation errors tend to be reported to a greater extent, thereby creating a stronger incentive and a more informed basis for finding solutions in the materials preparation design for preventing future errors. Supplier or 3PL ownership is not recommended from a quality performance perspective, as communication barriers that likely arise likely will hinder quality problem rectification and resulting in the preparation work being performed disconnected from the assembly.

Hence if possible given the context and the choice of location, the operator working in the materials preparation process should use **combined preparation and assembly**, or at least work on a rotation schedule so that assembly is performed some of the time, in order to acquire knowledge about the end product which can be utilized during preparation to better assess whether the correct component is picked. In case the operator works with full-time preparation, it is important to have a rotation schedule so that the same operator works across multiple processes to avoid patterns being learnt between components commonly picked together. As using a **production ownership** result in more efficient error rectification, it is the recommended setting for the process ownership. However, the materials preparation designer should consider ways of ensuring that errors are still reported properly, even though they are handled within the same department as assembly.

5.3.1.4. Policies

The batching policy, the storage assignment policy and the picking policy are all influential for the quality outcome. For the batching policy:

- If quality is the prioritized performance objective, then a single package batching policy should be used. Using any batching policy larger than one introduces the risk of making placement errors, due the multiple picking packages on the carrier. See Study example A (page 79) on for more details.

- If quality is not the prioritized performance objective but still important, there are different ways of reducing the amount of placement errors when a batching policy larger than one is used, for example by the design of the picking package (see section 5.3.1.7, page 53) or by the use of an effective picking information system (see section 5.3.1.9, page 53), and Study example A, page 79), or by using a picking policy where the picking packages are filled sequentially.

Concerning the storage assignment policy, the following points are important regarding the quality outcome:

- Similar components, e.g. left- or right-sided versions of the same component type, should be separated in the storage racks. Separating similar components in this manner may reduce the risk of the picker mistaking one part number for another.

- Separating similar components in order to avoid mistaking one part number for another may not only be a quality assurance during regular picking, but may also be beneficial if the operator needs to return a component that was wrongly picked to the storage package, as it avoids confusing two similar part numbers for each other.

- When using a moving picking package, the part numbers must be stored in the reverse order from which they are to be assembled, thus greatly restricting the possibility to separate similar components from one another.

- Dependent demands may also be exploited in benefit of the quality outcome in the storage policy design, as parts that are always picked together are stored together, thereby reducing the risk of incorrectly picking the second component if the first component is picked correctly.

A note regarding the effect of picking policy on the quality outcome, pointing at the difference between using sequenced supply or kitting:

- As the picking packages are completed in parallel in kit preparation the number of components in the picking packages may vary after a given order line has been completed. In contrast, when sequenced supply is used, the compartments are either full or empty, thereby providing a higher cognitive support to detect if any components were missing in previous order lines.

5.3.1.5. Layout and movement pattern

The layout and movement pattern design is, compared with many other design areas, relatively insignificant for the quality outcome, but may have an indirect effect on the quality outcome in its interaction with the storage assignment policy and with type of picking package carrier that is used. See section 5.3.1.4 for more details. The most significant variable within the layout and movement pattern design area for the quality outcome is the “positioning of key resources”, the working hypothesis being that the resources should be positioned so that the movement pattern throughout the picking tour is disrupted as little as possible when the resources are accessed. For example, the positioning of trash bins is important when it comes to discarding internal packaging, for which the aim should be to position the trash bins somewhere along the regular route which the picker travels, or on the picking package carrier, so that the operator is not disrupted every time the trash-bin has to be accessed. See section 5.3.1.6 for more details.

5.3.1.6. Storage packaging

The storage packaging can have an influence on the quality outcome. In particular, the following points regarding storage packaging should be considered by the materials preparation designer:

- Sensitive components need to be stored with internal packaging to avoid scratches, which leads to the frequent activity of discarding the internal packaging before the components are placed in the picking package. Internal packaging handling, when present in the materials preparation to protect the components from damage, introduces interruptions to the picking tour that in turn may cause preparation errors. The level of interruption caused can be minimized by properly considering the impact the handling of internal packaging has on the movement pattern during the picking tour, for example by means of the positioning of key resources. See section 5.1.3.4 (page 52) for more details.

- The storage packaging may not be a choice for the kit preparation process designer, as a certain choice can be deemed necessary by the component characteristics. When possible though, internal packaging that needs to be discarded during the picking tour should be avoided.

- Depending on the type of storage packaging that is used and whether the components are protected by internal packaging, the amount of empty packaging handling that is necessary during the preparation may vary substantially. If becoming frequent enough, as for example when using small plastic boxes for high-runner component variants, or with internal packaging used to keep the component in place in larger packaging types, the empty packaging handling could cause substantial disruption to the picking tour. The amount of disruption caused could be reduced by considering the manner in which the empty packaging is discarded, for example by locating the discarding point in an easy to reach location, for example on the top shelf of the flow racks. See also section 5.1.3.4 about "positioning of key resources".

- Using a materials exposure that allow visual control of the storage package contents, for example **tilted packages**, can allow for an improved ability to assess that the correct component is picked. However, if tilted storage packages are used, it has to be ensured that the contents are not at risk of falling out, which could damage the components and in turn compromise the quality. It is thus important to not tilt the packages more than is necessary for optimal materials exposure.

5.3.1.7. Picking package and carrier

The design of the picking package and carrier are important in regard to the quality outcome both directly and in interaction with the picking information system. The following points are emphasised here:

- When using a batching policy larger than one, making a correct placement is facilitated by having separate and fitted compartments for each component type – i.e. a picking package structure – that are filled in sequence. However, if component variants varies a lot in shape and size, it will be difficult to create customised slots that fits all variants of a component family.

- By designing a **structured picking package** by use of compartments for each component type, it is easier for the operator to notice if any components are missing or if too many are picked. Having compartments in the picking package allow the operator to verify which assignment is currently being worked on by counting the number of compartments with components in them. In contrast, when an unstructured picking package is used together with a pick-and-place-by-light system, losing track of the of the next step is more serious from a quality point of view, as it is more difficult to determine whether the last component was picked or not.

- Using a **stationary picking package carrier** can lead to the picker having to walk substantial distances while holding the components – especially for low-runner component variants – and there is a risk of dropping and hence damaging the components. Hence, from a quality standpoint, it is preferable to apply a moving picking package carrier, so that components never must be carried far.

Hence, a **structured picking package** is the recommended choice when the quality outcome is prioritized. The feasibility of using a structured picking package depends on the component characteristics, in terms of variability in shape and size for component variants within the same component family. Moreover, applying a **moving picking package carrier** will reduce the distances which the components must be carried, hence minimising the risks of dropping and damaging components, why a **moving picking package carrier** is recommended from a quality standpoint.

5.3.1.8. Materials handling equipment

The materials handling equipment may be important in its interaction with other design variables in regards to quality, but no direct effects have been observed over the course of the research project. An example of an indirect effect are how the storage racks may have to be modified in order to create efficient positions for the discarding points for empty packaging when flow racks are used.

5.3.1.9. Picking information system

The picking information system is central for the quality outcome in materials preparation. Designing the picking information to be an effective quality assurance does, however, require consideration to how other design variables are set. Study example A shows the outcome of an experiment where four picking information systems where compared on basis of the amount of picking errors observed when using them in a kit preparation process for two different batching policies.

The picking information system's impact on the quality outcome comes from the information medium, confirmation method and the information structure. The following hypotheses have been derived throughout the research project for relation between the picking information system and the quality outcome:

- Information media that applies **spatial information** (e.g. **light indicators, mixed-reality, augmented reality**) are more beneficial for the quality outcome than are media based on text-based or symbolic information. An exception is **speech prompts**, which seem to also promote a high quality outcome, likely due to the effect the speech prompts have on the pacing of the picking process, as it slows down the picking and thereby hinders mistakes from being made (especially in dense picking areas)

- Confirmation methods that can confirm that loca-

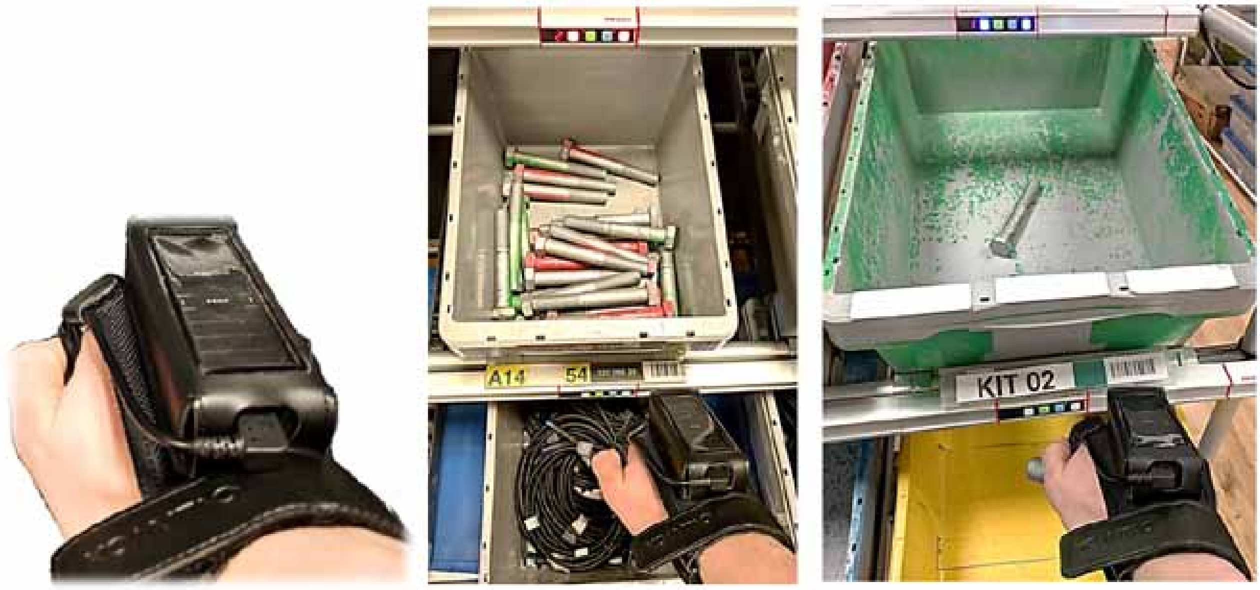

Figure 5.3: Example of a setup with a barcode ring-scanner as confirmation method. A ring-scanner worn on the wrist (left picture) is used for scanning a barcode on the shelf (middle picture) and for scanning a barcode on the cart (right picture) when components are placed in the kits.

tion has been visited promotes quality to a greater extent than confirmation methods that only control that an activity has been performed. Confirmation methods that can confirm that a location has been visited include **button-presses**, **proximity sensors** and **RFID-wristbands/gloves**. Voice-commands and barcode-scans – which require the picker to be in proximity of the picking location for reading the check-digits or scanning the barcode, respectively – are also beneficial from a quality standpoint. Using confirmation by order line – for example making a check-mark on a paper pick list or pressing a button on a monitor after all components on an order lines has been picked and placed – is disastrous from a quality point of view.

Relating to specific typed of information systems, there are adjustments in the design that can be made that promote quality, including:

- With **pick-by-light** used for picking components from the shelves, the “Christmas tree” approach should be avoided (meaning that all lights of the entire picking tour are lit up at once). Instead, only lighting one light at time is superior from a quality standpoint.

- With **pick-by-light** and batch preparation of kits, lighting up all placement locations at once can lead to all placements being completed before the placement confirmations have been performed, which compromises the quality outcome as the confirmations then are dissociated from the placement activities.

- Using **pick-by-light** and batch-kit preparation, missing the confirmation of a light indicator during the placements by leaving it lit after all placements are completed also dissociates the placement activity from the confirmation.

- To only **light up** one light at a time on the kit carrier would remove the possibility for the dissociations to occur, but would likely require more time to complete all the placements.

- The way that different systems verify that materials are replenished correctly, for example can effectively detect errors in the replenishment and, thereby, also prevent errors in the completed packages.

- How the information system **handles missing materials,** a function which often is available in **pick-by-voice** systems and in **pick-by-light** systems with an accompanying monitor on the carrier, is also beneficial for the quality outcome. Proper consideration of such functions when choosing and designing the picking information system is crucial for the preparation process to be able to manage variability in the materials supply, which is, thereby, also crucial for the quality outcome.

The recommended picking information design to promote the quality outcome of materials preparation is hence to use information media that applies **spatial information** (e.g. **light indicators, mixed-reality, augmented reality**) or **speech prompts**, and a confirmation method that can confirm that location has been visited, for example **button-presses**, **proximity sensors** and **RFID-wristbands/gloves**, or **voice-commands** or

barcode-scans. It is also recommended that adjustments that promote quality of any applied information system are evaluated when the implementation is made, for example in terms of what sequence, and when, the picking information for the next activity should be presented by the system.

5.3.2. Design for flexibility

To achieve a materials preparation design with a high flexibility level, in terms of both range- and response flexibility, the materials preparation design must be considered in term of how much variability the process can handle and what effort is required to make changes in the process design.

5.3.2.1. Planning and control

The key for flexibility in terms of the planning and control is effective communication regarding the materials supply to the preparation area and in regard to the rectification of preparation errors. Pull-based approaches for materials replenishment are preferable, for example two-bin systems or Kanban, as such systems require little re-planning upon production changes. For error rectification, standardised and effective communication channels must be available for the assemblers. If an error is detected in the assembly, communication pathways for getting the correct component delivered quickly must be available so that the assembler prioritises utilising the standard procedures over resorting to informal ad-hoc procedure, as for example cannibalisation of other kits at the assembly line or running over to preparation area to collect the right component.

5.3.2.2. Location

The location impacts the flexibility in two different ways:

1. With increasing distance from the assembly process, floor space is more likely to be available for extending the storage shelves to make room for more component variants, which improves the new product, modification, mix, and volume flexibility of the process – of course assuming the assembly process too can handle the changes. Locating the process in an **external facility**, **in the warehouse** or in a **separate area**, utilizing a **decentralized policy**, is likely to result in more floor space being available around the preparation area than next-to-assembly. The amount of floor space that will be available when the choice is made depend on the context.

2. The shorter the distance to assembly is, the higher the delivery flexibility becomes, as the transport time from the preparation area is to assembly is proportional to the distance. Hence, the highest delivery flexibility is achieved by locating the process **next-to-assembly**.

In regard to flexibility, the location design variable presents a trade-off between new product, modification, mix and volume flexibility—which benefit from locating the process further from the assembly process—and delivery flexibility, which instead benefits from locating the process next-to-assembly. To make the choice on location in regard to flexibility, the materials preparation designer should account for the context by considering:

- How often will new product introductions, ECOs, mix, volume and delivery schedule changes arise which requires the process to change? In the best case? In the worst?

If considerable amount of changes can be expected, the materials preparation designer should choose a location where the variability can be handled effectively, or at least make sure that the process can be moved to a location where the variability can be handled once it starts. A further question that could be asked in order to choose an appropriate location would be:

- How much floor space is available next-to-assembly? Is there enough floor-space available to handle any foreseeable new product introductions, ECOs, mix and volume changes?

If there is enough floor space available next to the assembly process for handling the foreseeable variability, then the recommendation is to locate the process there, in order for all flexibility types to benefit.

5.3.2.3. Work organisation

Whenever a change has to be made to the materials preparation design, the work organisation will impact the cost and lead time of making those changes, hence impacting the flexibility. Primarily within the work organisation design area, the **responsibility for industrial engineering tasks** and the **job role** of the operator impact the flexibility. Two points are emphasised below in this regard:

1. With higher organisational integration around performing industrial engineering tasks, less cost and a shorter lead time is required to make changes to process. More specifically, the closer the responsibility for making the changes is to the daily operation of the process, the less cost and the lead less time the changes will require[13]. A higher organisational integration around industrial engineering tasks

13) Changes here refers to both physical changes to the design, for example extending storage racks to make room for more components or rearranging the picking locations in storage racks to optimise the locations for picking following a product mix change, and to IT-system changes, for example updating picking location labels on the storage racks and updating which component numbers are stored at which picking location in the IT-system.

hence improves the new product, modification, mix and volume flexibility. Using a **dedicated support** would be optimal in terms of flexibility, followed by **in-house support**.

❷ A higher job role integration between materials preparation and assembly allows component numbers to be moved between the preparation area and the assembly, which improves both the ability to balance the workload in the preparation, as well as in assembly, and improves the ability size the material storage at the preparation area, as well as at the assembly process. A higher job role integration, by using for example **combined preparation and assembly**, thus improves the volume flexibility.

In regards to flexibility then, the recommendation is to use a **dedicated management** for the process, and **combined preparation and assembly** for the job design for the operator who performs the preparation work.

5.3.2.4. Policies

Depending on what storage assignment policy is used, different amounts of rearranging the storage may be necessary upon changes in production mix. Generally, the storage assignment policy impacts the flexibility as follows:

- The higher the degree of classification in the storage is, the more rearrangements of picking locations has to be made when the production mix changes. Specifically, a change in production mix means that the demand for individual component variants change in relation to each other. If there is a high degree of classification, component variants need to be moved in order to keep the movement pattern optimal at the preparation area.

For improving mix flexibility then, the degree of classification should be kept as low as possible, where a **random storage policy** would be the preferred option in theory. However, in practice, a random storage policy is likely unsuitable for preparation due to the additional requirements posed by the product structure, in regards to which most of the other design variables are chosen. Thus, in practice, a class-based policy or a dedicated policy are more realistic choices. If a random storage policy is considered a viable alternative however, the following considerations about picking package carrier should be made in regards to choosing the storage policy for improved flexibility:

- If the picking package is stationary during the picking tour, a randomised storage policy will reduce the time efficiency of the process, as the walking distances, and thus the walking time, are not optimized in any way due to the random picking locations. Thus, efficiency will be compromised by this option.

- If the picking package is moving during the picking tour, no rearrangements of picking locations will have to be made regardless of where they are located, as all picking locations will be passed every picking tour. Hence for a moving picking package, the walking distance remains constant for any storage assignment policy, why the randomised storage policy would provide the highest flexibility – as part numbers need not be re-arranged upon changes in product structure or demand – without compromising efficiency, as in the case of a stationary picking package. However, the feasibility of using a random storage policy with a moving picking package carrier would require that the picking packages are unstructured, and hence that the components can placed in the picking packages in any order.

5.3.2.5. Layout and movement pattern

In the impact on mix flexibility, the layout and movement pattern interact with the storage assignment policy. The guiding principle for the choice of layout and movement pattern in regard to flexibility is:

- If a moving picking package is used, the picking locations need not be re-arranged if the production mix changes, as the walking distance will always be the same regardless of where the component numbers are stored. Therefore, by using a moving picking package carrier, mix response flexibility will improve dramatically over using a stationary picking package carrier.

- However, to use a moving picking package requires that the picking package carrier is not too heavy to move throughout the picking tour, in case of manual transport, which depends on a combination of the batching policy, the number of components per picking package, and the weight of the components managed in the process.

5.3.2.6. Storage packaging

With a smaller packaging, it is more likely to be able to add additional picking locations upon new product introductions, ECOs or changes in production mix without reconstructing the material storage shelves. Hence using smaller packaging improves the new product, modification, mix, and volume flexibility of the materials preparation process. Hence, the guiding principle should be to use reduce the packaging size when possible by using **small boxes** to the extent possible, which when combined with an effective replenishment principle for example Kanban, maximizes the new product, modification and mix flexibility. Adding a box picking location – which corresponds to one part number – is also more likely to be possible without constructing or adding new shelves, since each box require comparatively small storage space, while adding a part number stored in a pallet require substantially more storage space and is

Figure 5.4: Example of a setup with button-presses as confirmation method. Buttons are positioned above each picking location (left picture) and above each kit container on the cart (right picture). The picker presses the buttons to proceed to the next activity shown by the light indicators in this example.

thus less likely to be added without having to build new shelves. Of course, whether or not a new part number can be added, regardless of whether it is stored in a box or pallet, depends on the amount of empty space that is available in the storage racks. It should also be noted that the choice of storage packaging may not be up to the materials preparation designer, as some larger parts may require to be stored in a pallet or in a large box, and any changes of storage packaging likely must be coordinated with other divisions of the company, for example procurement.

5.3.2.7. Picking package and carrier

The picking package design is important in regard to flexibility in terms of how much it has to be changed following changes to the part numbers it is designed to hold. When new component variants are introduced as the result of a new product introduction, a high degree of customisation of the picking package can be both costly and time consuming to adapt to fit the new component variants. On the other hand, if individual component variants do not have a specific position they are intended to be placed in, as in an **unstructured picking package** is used, the introduction of new variants will not require any changes to be made. Hence, for improving new product flexibility, the picking package should have a low degree of customisation and ideally be unstructured. A good option for flexibility may also be to use a semi-structured picking package design, where several smaller containers are available inside the main package (like the babushka-doll, see section 4.7.1 (page 39). The picking package carrier interacts strongly with the storage assignment policy in its impact flexibility, see section 5.3.2.5 (page 56) for more details.

5.3.2.8. Materials handling equipment

There are two aspects in regards to the materials handling equipment which may impact the flexibility:

❶ If **lifting supports** are used in the process, e.g. using a **traverse bolted to the floor**, will create substantial costs if the process design needs to be changed. In particular, adding picking locations to the process will be costly, why a high level of mechanisation of the lifting supports will reduce the new product, modification and mix flexibility of the process.

❷ The storage rack design will impact the ability to rearrange the storage, for example moving around shelf-sections, which may be necessary when the production volume or the production mix change, thereby impacting the volume and mix flexibility. Pipe flow-racks are more easy to rearrange than shelf-sections and are hence preferable from a flexibility point of view.

Regarding the ❶ first point, the lifting support should be chosen and designed so it is possible to change if the layout of the process needs to be changed as a consequence of new product introductions, modifications or changes in mix. See Design case 4 on page 68 for an example of how a traverse can be flexibly integrated in the design. It should also be noted that if lifting support can be effectively integrated in the materials preparation design, lifts of heavy components may be possible to remove entirely from the assembly process, where the assembler can collect the component from the picking package instead.

Regarding the ❷ second point, wheel-based pipe flow racks are the preferred choice for storing boxes, which allow whole shelf-sections to be moved around with little effort. Also, there are different solutions for shelves which may improve flexibility as well, for example shelf-attachments that are supported by hooks instead of bolts.

5.3.2.9. Picking information

When component numbers need to be arranged or when new component numbers are added to the process and the storage racks need to be extended, the picking information system may influence the flexibility of handling such changes. In particular:

- If the picking information system requires shelf-labels that present for example the component number, barcodes or check-digits, then these labels need to be updated when the picking locations change, thereby reducing the new product, modification and mix flexibility.

- If the storage racks need to be extended and there are cables needed for each picking location, then new cables need to be added for the new locations, thereby reducing the new product flexibility.

- All picking information systems require an update of the IT-system, but different systems require different amounts of administration.

- If there is a high degree of organisational integration around industrial engineering tasks – meaning that tasks related to changing the process are performed by people working close to the process, e.g. the production or logistics engineers responsible for the process' daily operation – the cost and lead time associated with changing the picking information can be reduced for any picking information system (see section 5.3.2.3, page 55, for more details).

In general when choosing among picking information systems, the following ranking may be used in regards to flexibility:

- **High flexibility:** Printed labels and paper pick lists only require links in the IT-system between location and new component variants, hence little administration for making changes and the changes can be made by the process managers (production or logistics engineers)

- **Medium flexibility:** Pick-by-voice also requires new labels for check-digits, RFID-scanning requires tags to be re-mapped, barcode scanning requires new barcodes to be printed, hence somewhat more administration and tasks that might require support from external parties

- **Low flexibility:** Pick-by-light requires cables, light-indicators, and light-indicators to mapped for new component variants, hence substantial administration and likely requires support from external parties

5.3.3. Design for productivity

Designing the materials preparation process for productivity has the aim of minimising the time spent by the picker on anything but the picking activities, and ideally reducing the time required to perform the picking activities. Productivity is here also about using as little as possible of other resources besides time to fulfil the preparation work tasks. This includes inventory held in the process and the amount of transports to and from the preparation area, as well as how efficiently changes can be made to the process design.

5.3.3.1. Planning and control

The key for efficiency in terms of the planning and control is effective communication regarding the materials supply to the preparation area and in regard to the rectification of preparation errors, see section 5.3.2.1 about flexibility for more details. Furthermore, to achieve productivity, it is essential that the Bill of Materials (BoM) is maintained updated regularly, so that it reflects the current product structure. Without and up-to-date BoM, a lot of rework will be required, and the productivity of the system as a whole will be reduced.

5.3.3.2. Location

The location relative to assembly and the centralisation policy affects the efficiency of the preparation in the following ways:

- A **decentralised policy** away from assembly will likely yield more floor-space and less constraints when designing the picking area, than for example locating the process next to the assembly process, thereby allowing more efficient layout and movement patterns to be used.

- Using a **decentralised policy** will likely require the same part number to be presented at multiple preparation areas—as some part numbers are needed in more than one step in the final assembly process—leading to a higher total amount of inventory in the system for those part numbers, as well as a higher amount of transport required for replenishing materials at the preparation area.

- If instead a **centralised policy** is used, part numbers used in multiple steps in the final assembly process can be stored closer together, perhaps even having a single picking location for multiple preparation processes, thereby reducing both the amount of inventory in the system as well as the amount of transport required. It should be noted that using fewer picking locations for part numbers for reason of reducing inventories and transports can lead to reduced efficiency in the picking process, as longer travel distances to collect the required components may result. Furthermore, while using fewer picking locations for the same part number may lead to fewer transports overall, it may lead to longer transport routes being required.

- A centralised policy, or a decentralised policy with a combined job role with assembly, will improve the possibility for work load balancing, thereby reducing the amount of idle time for the individual operator. In the **centralised policy**, the work load balancing is achieved by having operators rotating between preparation processes, while with the **decentralised policy located close to assembly**, the work load balancing is performed by moving assembly and preparation activities between the assembly and the preparation processes as part of the job design.

- The transport requirement for a given location is made up of the transports required to replenish part numbers stored at the preparation area, as well as the transports required to for delivering the prepared materials to the assembly process. Using a **location in the warehouse**, where the bulk storage of materials is located, will always minimise the transport requirements for replenishing materials to the preparation area. However, if the batch size is small, a location in the warehouse will result in substantial transport requirements for transporting the prepared materials to the assembly process. A **location next-to-assembly** will have the opposite effects – creating a higher transport requirement for replenishing the preparation area, but reducing the transportation requirements for transporting the prepared materials to assembly – thereby making a smaller batch size viable to use. Moreover, preparation errors will require less resources to correct if the preparation area is close to the assembly process. In general, it is in general more efficient on a system level to locate the preparation area close to the assembly process.

Choosing the location in order optimise the efficiency is hence dependent on the context. If there is enough floor space available next to the assembly process for allowing an unconstrained layout design, or if an efficient layout design can be achieved regardless of any floor space constraints, and if the replenishment to the preparation can be designed to also be efficient – for example by using tugger- continuously running tugger-train routes – then a location next-to-assembly would be the preferred choice.

5.3.3.3. Work organisation

Work organisation impacts the efficiency mainly regarding the operator job role, but also in terms of the responsibility for industrial engineering tasks and the process ownership. The working hypothesis is that the key tenet of how the work organisation design impacts the efficiency, is in terms of the degree of organisational integration, referring to the bureaucratic distance between the different functions that enable the materials preparation. A higher degree of organisational integration generally leads to a higher efficiency of the materials preparation. The following points exemplifies this notion:

- Using **combined preparation with assembly** improves the possibilities for work load balancing, where preparation tasks can be balanced with assembly tasks, either by moving some activities of the assembly work to the preparation area, or by moving some part numbers to the assembly area to be picked by the assembler. Here, the accuracy and quality of the balancing process is essential for efficiency and it is crucial that the production engineers have high enough competence to perform the balancing so as to make the final result efficient. Furthermore, it is crucial that operator – who performs both preparation and assembly with this option – has high enough competence to perform both sets of work tasks (preparation and assembly).

- If the process is governed by the production department (i.e. **production ownership**) the communication route between preparation and assembly will be more direct than if a logistics or third-party ownership is used, thereby improving the efficiency of decision making related to the design and operation of the preparation process.

- By the same logic, if the preparation process have **dedicated management** team (both legally and practically) any problems or alterations to the design can be made with a shorter lead time, more frequently and possibly also with more precision – meaning that the design alterations are made with more consideration to how the process actually functions since the management team is highly familiar with how the process ticks – thereby improving the efficiency of the management of the process.

The degree of organisational integration that can be attained does however depend on the settings of other design variables, for example where the process is located or what type of picking information system is used (as some systems, e.g. most variants of pick-by-voice, may require expertise that extend beyond the in-house competencies).

5.3.3.4. Policies

The policies used in the materials preparation are highly influential on the efficiency during the picking tour, where the batching policy also is important for the transport efficiency for transports of prepared materials to the assembly process. The storage assignment policy also has an impact on the efficiency of handling production mix changes. The following points highlight the policy settings which promote efficiency in the materials preparation:

- Using a **batching policy with multiple picking packages** being completed per tour allows multiple components to be picked at the same time, as the needs of multiple picking packages are handled in parallel. Research has shown that picking multiple components at once improves the time efficiency of the picking tour substantially .

- However, due to the risk of making placement errors when using a **batching policy with multiple picking packages**, a placement confirmation is often necessary to ensure that the components are placed in the correct package. In dense picking areas, for example where the storage consists of mostly small plastic boxes on multiple shelves, the presence of placement confirmation can reduce or even reverse the time efficiency of using a batch over a single package policy. Hence, if the preparation area is dense, a single package policy may preferable over a batch policy from an efficiency standpoint, depending on what type of confirmation method is applied. See Study example B (page 80) for more details.

- For transport efficiency from the preparation area to the line, using a batching policy with multiple picking packages will reduce the number of total transports needed, which if the location is far away from the assembly process will dramatically reduce the transport requirement. Therefore, a **single package policy** can only be recommended for locations close to the assembly process.

- If a high degree of classification is used in the design of the **storage assignment policy**, for example class-based assignment where high-runners are stored closer to the picking package carrier, the picking locations will need to be rearranged when, for example, the production mix changes, thus leading to an inefficient design in handling production mix changes.

- However, a high degree of classification in the s**torage assignment policy** will ensure that high-runner part numbers are always stored closest to the picking package, leading to the shortest possible travel distance for the part numbers picked most frequently, thereby significantly improving the time efficiency during the picking tour.

- When a moving picking package carrier is used and the movement pattern over the picking tour passes all picking locations, there is no need for using a **classification in the horizontal direction**. However, a **vertical classification** may still be advisable, to ensure that high-runner part numbers are always picked from the most ergonomically favourable height.

- In the design of the **picking policy**, the efficiency benefits from more components being picked per activity. When a batching policy with **multiple packages** is used, choosing the picking policy so that multiple components of one part number can be picked at once is preferable from an efficiency perspective (although not from a quality perspective), while if a **single package policy** is used, being able to pick several part numbers before placing them in the package is preferable from an efficiency standpoint.

5.3.3.5. Layout and movement pattern

The layout and movement pattern are important for time efficiency in particular, but also interacts with the storage assignment policy. A guiding principle for choosing the layout and movement pattern in regard to time efficiency is to minimise the travel distance during the picking tour. The following points should be considered:

- When the picking aisle is narrow, an **II-type layout principle** results in the shortest total travel distance for the picker and is hence in most situations the most time efficient choice of layout. However unless the picking information is intelligently designed, in terms of providing effective guidance to the picker for collecting components from alternating sides of the aisle, much of the efficiency gained from the short travel distance is lost due to picker having to excessively search for the picking location.

- A **U-type** layout results in twice the travel distance of the II-layout, but can be beneficial for efficiency when the preparation area is small to medium size and contains fairly few part numbers, especially if the picking aisle is wide. Another benefit of the U-type layout is that the picker only has one side to pick from and thereby do not have to turn during the picking tour, which reduces the search time.

- Another option for achieving high time efficiency with a moving picking package in case there are many component variants handled in process—i.e. when picking aisle is long—is to use an **H-type layout** to improve the efficiency of a regular II-type layout. In the H-type layout, the picking locations for low-runner part numbers are assigned to the end of the aisle and only visited sparingly, not part of the main route.

- If there are many component variants handled in the same process, the picking aisle may become very long, and the picking involves few components picked for every meter travelled, and the picking occurs at a low frequency. In these circumstances, using a moving picking package may be less efficient than using a **stationary picking package**, as the picker will only sparingly visit the picking locations for the low-runner part numbers located farthest away from the picking package carrier. The same organisation of the shelves as when a moving picking package carrier is used can be used for a stationary picking package carrier as well. The difference will be that the picker travels back and forth between the stationary picking package carrier and the picking locations in the storage racks.
- In terms of space efficiency, the I-type layout principle only require access for the materials supply to replenish materials from one side of the preparation area. For the other layout principles (**II-type** and **U-type**) the materials supply needs access to both sides of the preparation area in order to replenish materials. However, when multiple workspaces are located close together, the total floor-space requirements will be less for II-type and U-type preparation areas, as the aisles for materials replenishment can be used overlapping. Therefore, in terms of floor space efficiency, the II-type or the U-type layouts are preferable.

5.3.3.6. Storage packaging

Using smaller storage packaging will reduce the travel distance over the picking tour, compared to larger packaging, thereby be advantageous for time efficiency. Pallets are often large and require the picker to walk around the pallet and access the materials from the long-side, and this can generate substantial time variability losses in the process. To attain high levels of efficiency during the preparation, the materials should be presented in small packaging, for example **small plastic boxes**, on multiple shelf levels. Smaller packaging also typically do not require internal packaging to be present inside the package to hold the components in place (as typically larger packaging do), which further decreases the efficiency from the internal packaging having to be discarded. The type of packaging that can be used does however to a large extent depend on the component characteristics, in terms of size, shape, weight and fragility, but the principle as far as time efficiency is concerned, should be to use the smallest packaging, and hence the smallest unit load, possible.

5.3.3.7. Picking package and carrier

For the design of the picking package and the picking package carrier regarding efficiency, the key tenet is to use a design which allow the placements of components in the picking packages and the movement in the picking aisle to be performed as effortless as possible. Below are a few points related to this tenet:

- In the design of the picking package carrier, the choice between using a **moving picking package carrier** – that the picker brings with during the tour – and using a **stationary picking package carrier** – that remains in one place during the tour – has to be made. The deciding criteria for this choice regarding efficiency is which alternative that result in the shorter travel distance during the picking tour. A general guideline would be that if the proportion of low-runner component variants at the preparation area is large, then a **stationary carrier** would lead to the shortest total travel distance and hence be optimal for productivity.

- When the picking aisle is long and a higher degree of classification is used for the storage assignment policy, using a **stationary picking package carrier** is generally more efficient. This is due to that the low-runner component variants, which are stored farthest away from the picking package carrier, are only rarely visited, why the total travel distance for completing one picking package will be smaller than if all picking locations are passed by, as with the moving picking package carrier.

- A moving picking package carrier would preferable from an efficiency perspective when the picking aisle is shorter and there are fewer part numbers managed in the process. Even for longer aisles, the H-type layout principle can make the moving picking package carrier a viable option efficiency wise.

- When considering **using a moving picking package carrier**, the extra effort for pushing the moving picking package carrier should also be considered. The required effort depends on the total weight of the picking packages once they are filled, which in turn depend on the weight of the individual component variants and the batch size used. In case the picking package carrier becomes heavy to push once the packages are filled, automated options for moving the carrier, for example AGC's, could be considered.

- In II-shape and U-shape layouts for long aisles, a combination of moving and stationary picking package carrier may be beneficial for productivity. With this setup, the carrier would be moved some distance into the aisle and left stationary there until all components in the immediate area has been collected, before it is moved another bit into the aisle and the process is repeated.

Figure 5.5: Example of a setup with double RFID-reading wristbands as confirmation method. The wristbands (left picture) automatically scans an RFID-tag placed on the brim of the storage container (middle picture) when components are picked, and automatically scans an RFID-tag on the brim of each kit container (right picture) when components are placed in the kits.

- A moving picking package carrier that is handled manually should have good manoeuvrability, and perhaps also make use of **guiding rails in the floor** for improving the stability during picking tour. If guiding rails are used, they should be placed so that it is practically impossible to trip on them, for example by placing them alongside or under the storage racks.

- For the design of the picking package from an efficiency standpoint, any additional requirements for positioning of the components when placing the components in the package will reduce the time efficiency during the picking tour.

5.3.3.8. Materials handling equipment

The types of materials handling equipment needed in the materials preparation process are highly dependent on the context. For example, the need for lifting support equipment depends on the weight of components managed in the process, and, of course, the use of lifting support equipment will impede efficiency during the picking tour. Also, the need for different tools related to packaging handling, for example blade-knifes, scissors or band-cutters, all need to be considered in terms of accessibility and use during the picking tour in order to reduce any handling time losses that may arise.

5.3.3.9. Picking information

The impact of the picking information design on the efficiency is substantial and highly dependent on the settings of other design variables and on the context. The research project studied the role of the picking information system for efficiency during the picking tour. The reader is referred to Study example B (page 80) for a summary of that study's results.

- In dense picking areas, information mediums utilising spatial information result in superior picking efficiency, for example **light indicators, mixed-,** and **augmented reality**. This is due to the overview of the picking are these types of media provide, in addition to the almost non-existent need to interpret the picking information – which there is no time for in dense picking areas – associated with these types of media.

- The confirmation methods that are beneficial for efficiency are such that require no extra motions for the confirmations to be performed. This includes **RFID-wristbands/gloves**, and **button-presses** (only small extra motion when reaching for the button).

- It should be noted that the requirement for having confirmations associated to picking components from storage (pick-from confirmation) and for placing components in the picking packages (place-to confirmation) when batch preparation is applied, both reduce the picking efficiency in benefit of improved quality. From an efficiency standpoint, confirmation by order line (where a single confirmation is performed to mark the order line as complete, but no individual pick-from or place-to confirmations are made) is beneficial for picking efficiency, but likely is disastrous from a quality standpoint.

5.3.4. Design for ergonomics

Ergonomics is a central concern for in the design of any manual work jobs. Having sound ergonomics in the process will indirectly lead to both improved quality outcome and improved productivity. When considering the materials preparation design from an ergonomics perspective, the crucial decisions for achieving a satisfactory musculoskeletal load are related to the layout and movement pattern, the storage assignment policy, the storage packaging, the picking package and carrier, and the materials handling equipment. Concerning illumination and visual conditions, both the materials handling equipment and the picking information system play a crucial role, while the planning and control, the work organisation, and the design of the picking information are crucial for ergonomics.

5.3.4.1. Planning and control

The planning and control design area can be of importance for the psychosocial environment to the extent that the picker has awareness of and can influence the work pace. In general, if the knows how he or she is doing in relation to the takt and the workload is set so that the operator has some flexibility in being able to **work ahead of schedule** – to have some longer idle time before upcoming jobs – the operator is able to influence the work pace, which is beneficial for the psychosocial environment. However, the possibility to buffer orders in this fashion should be limited to **one or two batches**, as more than that risks that the prepared batches gets put out of sequence, thereby creating quality problems for the materials supply or in the assembly.

5.3.4.2. Location

The location can be important for ergonomics in the interaction with other design variables and the context. For one, the interaction between the location and the work organisation regarding the ability to work load balance between materials preparation processes or between materials preparation and assembly work tasks is indeed relevant ergonomics in creating work task variety. This mechanism is described further in the next section (5.3.4.3 Work organisation). Moreover, when the preparation is performed in the warehouse, it is common that picking is made from pallets and it can be difficult to achieve a job design with good ergonomics when picking is made from pallets.

5.3.4.3. Work organisation

The key tenet in the work organisation design area for promoting a satisfactory psychosocial milieu is to create work task variety. This can be achieved by either the job schedule or the job role design.

- Using a **combined job role** between preparation and assembly will improve the work task variety compared to only performing materials preparation, thereby improving the psychosocial milieu.
- If the job role instead is **full-time preparation**, then a **rotation schedule** will allow the pickers to work in different materials preparation process during a single shift, which promotes work task variety and thus improves the psychosocial milieu.

5.3.4.4. Layout and movement pattern

The layout and movement pattern design is mainly important regarding ergonomics in the effect on **the amount of turns** which the picker has to do during the picking tour. with a moving picking package carrier, the layout types **I-shape** and **U-shape** remove the necessity for the picker to turn during picking, as only one side of the aisle is picked from at a time. In contrast, the **II-shape** layout requires the picker to turn from one side of the aisle to the other during the picking tour, which is creates a higher musculoskeletal load.

5.3.4.5. Policies

In terms of the policies used in the process, it is primarily the storage assignment policy that is of importance to the musculoskeletal workload, in particular in regard to how it influences the picking height. As opposed to the horizontal storage assignment policy – for which the aim of the design is to optimise the location of the different part numbers for the shortest average travel distance during the picking tour – the aim of the **vertical storage assignment policy** is to locate the high-runner component variants at the **optimal picking height** from an ergonomics standpoint. The optimal picking height depends on the height and reach of the picker, but always corresponds to the picking position where the amount of bending is minimal and should never be above shoulder height for the picker, see Figure 2.1 for more details. In a pipe flow rack with boxes and three shelf levels, the optimal picking height will likely be found on the middle shelf level, but a specific analysis for each individual situation should be made, for example by means of the RAMPII framework discussed in subchapter 2.4 (page 15).

5.3.4.6. Storage packaging

Regarding storage packaging, research is conclusive that picking from **boxes** is preferable over picking from **pallets** in terms of musculoskeletal load, assuming that picking the optimal picking height is considered in the design.

- **Boxes** generally require less space than pallets in the storage racks and are therefore easier to optimise the position for in terms for picking height, angle of exposure and offset between shelf levels. Thus, in most situations, using boxes as storage packaging is optimal from an ergonomics standpoint.

- Picking from **pallets** placed directly on or slightly above floor-level (on a shelf) unavoidably leads to bending when the materials in the pallet are accessed. However, different means of materials exposure can improve the ergonomic conditions when picking from pallets, for example placing the pallet on a shelf and using less pallet frames.

- A picker usually cannot reach the components at the short-end of a pallet when standing at the other short-end. Favourable for ergonomics when picking from pallets and there no room to walk around the pallet (for example in a compact picking area designs that conserve floor-space) is to use pallet sliders in the storage rack so that the pallet can be pulled out into the picking aisle. **Pallet sliders** allows the material to be accessed either from the short end of the pallet or from one of the long ends. See Design case 5 (page 75) regarding pallet sliders for more details.

- Research has shown that storing the pallet on a cart with a **tiltable fixture**, that allows the pallet to be tilted towards the picker, does not lead to improved ergonomics compared with picking from a horizontal pallet. However, if the pallet is tilted and the components in the pallet falls towards the lower short-end of the pallet, then the ergonomics can improve. To use this option of course assumes that the components are not damaged from falling in this manner.

5.3.4.7. Picking package and carrier

The design of the picking package and the picking package carrier is crucial for the musculoskeletal load during the preparation work. Below are a few guidelines related to the design of the picking package and of the picking package carrier from an ergonomics standpoint:

- In case of a moving picking package carrier, the total weight of the carrier when all picking packages are filled should be considered in the design. If the starting force or the continuous force required to move the carrier is large, then alternatives to manual transport should be considered, for example using an AGC or using a driven carrier controlled by the picker. See Table 2.6 (page 19) for recommended limits in terms of starting and continuous force for manual handling of the carrier.

- Either if a moving or a stationary carrier is used, the height of the picking packages should follow the same guidelines regarding optimal height as the picking locations, per the guidelines in Figure 2.2 (page 14) and in the RAMPII framework. It is crucial that positions of the picking packages that require the picker to overextend, bend or to frequently have the arm above shoulder height are avoided when the carrier is designed.

- If structured picking packages are used – which have specified slots for the component types part of the completed package – it is important to make sure that the components can be placed in the picking package without the need of much force in the picking package. The type of grip, the movements of the wrists and the wrist postures are important considerations in the design of the component type specific slots in the package. See Figure 2.1 (page 16) for more details on recommended limits.

- With regard to handling of the picking package carrier, using a rack to hold the complete picking packages can beneficial from an ergonomics point of view compared to handling heavy boxes. If boxes are used as picking package containers, then solutions involving roller-conveyors could be considered, where, for example, roller-conveyors are used for moving the picking packages from the carrier onto the transport vehicle, that could be, for example, a tugger-train.

5.3.4.8. Materials handling equipment

The choice of materials handling equipment is crucial for ergonomics, both in terms of the chosen storage rack types and in terms of the use of lifting supports when heavy parts are managed.

- Generally, the less effort that is required to reconfigure **storage racks**, the more positive is the impact on ergonomics. In this sense, **wheel-based flow racks** and shelves for pallets that have **bolt-free attachments** are preferred from an ergonomics perspective. Also, solutions for improving the materials exposure should also be considered as far as ergonomics is concerned, for example manual or automatic pallet sliders (see design case 5, (page 75) in the shelves or **fixtures that allow pallets or boxes to be tilted**.

- Lifting supports should be used in the process when individual components exceed a weight limit. The exact limit for when lifting supports are needed depend also on the shape and form of the component being handled, as well as on the height the pick is made from. General guidance on component weights that require lifting supports from the RAMPII framework can be found in Table 2.5 (page 18).

5.3.4.9. Picking information

Regarding picking information and ergonomics, it is mainly the information medium which has been shown to have an impact on ergonomics, manly in terms of the psychosocial milieu, noise and visual conditions.

However, the research project has also indicated that the confirmation method and the information structure may also have an impact, the former in terms of musculoskeletal load and the latter in terms of psychosocial milieu.

- In dense preparation areas, the **speech-prompts** in a pick-by-voice system may become tedious for the picker, especially when picking is performed for longer durations of time, and is overall a poor option for creating a sound psychosocial environment. However, in less dense picking areas, there is a longer pause between speech-prompts, which lessens the tedium. Further, the use of speech-prompts as information medium will generally prevent the picker from having any other type of auditory input, for example radio headphones.

- Research studies[15] has indicated that some types of **smart-glasses** and **head-up displays** can lead to visual fatigue symptoms if used for extended periods of time. However, the research referred to here has only tested rudimentary types of these types of systems and the full extent of the impact on visual fatigue is yet to be fully understood, and more testing and research in this area is required. The materials preparation designer should however consider the risk of some users experiencing discomfort from using these types of systems, suggesting thorough evaluation before these types of systems are fully adopted.

- The confirmation method may have an impact on the musculoskeletal load if the method used requires repetitive motions of the fingers or hands. For example, repeatedly clicking a scanning button, either **ring-scanner or hand-held**, or pressing small or obtuse **light-indicator buttons**, may lead to discomfort if done too frequently. Special consideration should taken when picking is performed with high frequency in dense preparation areas. The reader is referred to Figure 2.1 (page 16) regarding recommended limits in the RAMPII framework for repetitive motions by the hands and fingers.

- As with the speech-prompts, using **voice-commands** to confirm activities may also become tedious for the picker if they are required to be performed too frequently, for example in high density preparation areas.

- Regarding the information structure, a general principle is that the less interpretation that must be performed by the picker in order to know how the next activity is supposed to be performed, the more beneficial it is for the psychosocial milieu. On this note, systems which link the pick- or place location immediately with the provided information, e.g. **light-indicators** at the picking locations or **augmented reality type pick-by-vision systems**, are generally more beneficial for the psychosocial milieu than are systems that require an intermediate interpretive step, for example reading from a **list** or listening to a **voice-prompt**.

5.3.5. Design for cost

The meaning of designing the materials preparation process for cost are twofold. One, it means to be cost efficient in the design process and choosing the design variable options that add up to the lowest investment cost, and two, it means to choose the design variable options so that the performance levels of the other four performance objectives (quality, flexibility, productivity and ergonomics) are optimised. In fact, over time the effects from the performance regarding the four other performance objectives will likely marginalise the investment cost (the return on investment time is of course dependent on the size of the initial investment and scale of operations), why the focus of the materials preparation designer should be on choosing a design that benefits the performance objectives. The priority among the performance objectives to achieve the lowest cost will depend on the context, for example on how the company's overall strategic goals are formulated. However, some general guidelines can still be formulated around how the design should be chosen to minimise the cost, summarised in the points below.

- Achieving a high **quality** outcome is likely key to optimise the cost in most contexts. If many errors occur in the materials preparation process, the errors need to be rectified somehow which will cause ad hoc situations in the system, resulting in rectification costs. Additionally, if for example the localisation is chosen far away from the assembly, the quality problem rectification costs will increase by a factor that is roughly proportional to the distance from the line at which the process is located, and there will be effects on both the assembly and end-product quality.

- **Flexibility** will be a key driver for cost in contexts where changes in product structure occur often or when new end-product models are introduced frequently. The flexibility cost will likely also vary between different materials preparation processes,

15) Klein-Theyer, A. et al. (2016). "The impact of visual guided order picking on ocular comfort, ocular surface and tear function". PLoS ONE, 11(6), pp. 1-9.

depending on how often changes happen to the product variants handled in each particular process.

- **Efficiency** is directly proportional to the cost of the system and design choices made to improve the efficiency will have larger effect on the overall cost the larger the total picking volume is. For example, a design choice that improves the picking efficiency by a few seconds per picked component will have a more substantial effect on the total cost in systems where millions of picks are made each day, compared to a system where only a couple of thousand picks are made per day.

- **Ergonomics** differs to an extent from the other performance objectives in terms of its influence on cost, as there is no justifiable way of compromising ergonomics to the benefit of cost reduction. However, a design in which the ergonomic effect has been carefully considered will overtime be superior also in terms of cost, as the process will provide a non-strenuous work environment. Furthermore, improved ergonomics are usually associated with a reduced personnel turnover, which also reduces the cost.

To design the materials preparation process from a cost perspective hence implies that the designer consider the provided documentation for choosing the design variables in alignment with the other performance objectives (see sections 5.3.1, page 50, to 5.3.4, page 63) in combination with the specific contextual setting for which the materials preparation design is being made. Furthermore, a driver for introducing materials preparation in the production system is to reduce the overall system cost. Achieving high performance levels of the materials preparation that reduce the cost associated with materials preparation will contribute to reduce the total costs of the production system.

5.4. Design for performance

Given the discussions in the previous section (section 5.3) concerning the various design variables related to the performance objectives, the various recommendations of the design variable settings for the five performance objectives are here summarised in Table 5.1.

Table 5.1: The recommended design options for the five performance objectives, summarising the discussions in section 5.3.

Design variable	Design for Quality	Design for Flexibility	Design for Productivity	Design for Ergonomics	Design for Cost
Planning and Control	• Keep preparation error records • Use formal rectification procedures	• Effective communication with materials supply and assembly	• Effective communication with materials supply and assembly	• Work schedule flexibility	• Optimise for quality
Location	• Next-to-assembly • Centralised	• Warehouse (new product-, volume- and mix flexibility) or next-to-assembly (delivery flexibility)	• Context dependent, see section 5.3.3.2 (page 58)	• Designed in relation to work organisation.	• Optimise for quality and productivity
Work Organisation	• Combined job role (full-time preparation if correlated demands) • Production ownership	• Dedicated management • Combined job role	• Combined job role • Production ownership • Dedicated management	• Combined job role • Job rotation	• Combined job role • Production ownership
Policies	• Single-kit • Separate similar components (not fully-correlated)	• Low degree of classification (e.g. randomised storage policy)	• Batch (low density) or single-kit (high density) • High classification (e.g. dedicated)	• Vertical storage assignment policy (high runners at optimal picking height)	• Optimise for productivity then quality
Layout and Movement Pattern	• Position key resources to avoid disruptions to the picking tour	• Moving picking package (if possible)	• II-layout	• I-type or U-type	• Optimise for productivity
Storage Packaging	• Minimise disruption from packaging handling • Tilted packages	• Small boxes	• Small boxes	• Small boxes • Tilted packaging	• Optimise for flexibility
Picking Package and Carrier	• Structured picking package	• Unstructured picking package	• Stationary picking package carrier (low density) or moving carrier (high density)	• Ergonomic considerations in the design	• Optimise for productivity
Materials Handling Equipment	• Avoid disruptions to picking tour	• Low mechanisation level • Wheel-based shelves and racks	• Use as little as possible	• Wheel-based shelves and racks • Bolt-free shelf attachments • Lifting supports	• Optimise for productivity, then quality and flexibility
Picking Information System	• Functions for material supply issues • Indicate sequentially	• Paper pick lists without confirmation	• Context dependent, see study example B in section 6.10 (page 80)	• Light-indicators or augmented reality	• Optimise for flexibility and quality

Summary of chapter 5
A design framework

This chapter has tied together the previous chapters of the handbook by presenting a design framework. In subchapter 5.1, an overview of the various design options was provided in form of the design mapping framework (Figure 5.1). This framework can be applied when selecting a materials preparation design to keep track of which options are available, and what the current design consists of. The framework outlines all design options for each of the design variables which are considered in the current book. However, there may be other design options available in some contexts, and surely additional options exist too, but if the reader takes into consideration the options presented in the current framework, he or she would be provided with a broad basis for making sound design decisions.

In subchapter 5.2, a design procedure was proposed, demonstrating in which order the design variables can be selected. Since some of the design choices affect other design choices, the procedure highlights and prioritises the various design choices. The design procedure was represented as semi-sphere with different layers. Outside of the semi-sphere is the context, which affects most of the design choices. In the first layer are the choices related to planning and control, the location, and the work organisation. In the second layer are the choices related to the policies and the layout and movement pattern. In the third layer are the choices related to the storage packaging, the picking package and carrier, and the materials handling equipment. In the innermost layer is the picking information. Even though viewing the design procedure in this way may give appearance of a linear design process that is carried out by starting in the outer layers and progressing inwards, it is crucial that the design process is carried out iteratively so that a suitable combination of the design settings can be achieved that yields the desired performance.

In subchapter 5.3, the various design options where considered in light of the desired performance objectives, where each performance objective was discussed in a separate section by of how the design options affect that performance objective. Each of the performance objectives were discussed, including design for quality (section 5.3.1), design for flexibility (section 5.3.2), design for productivity (section 5.3.3), design for ergonomics (section 5.3.4), and design for cost-efficiency (section 5.3.5). For each of the five performance objectives, the relevant design options of the design variables were discussed and recommended settings were presented.

Finally, in subchapter 5.4, the recommended settings of the design variables for achieving desirable levels of the five performance objectives are summarised in a table (Table 5.1). This table can be utilised as a condensed overview of the various options, were further details can be studied in other parts of the handbook.

The chapter as a whole may be utilised by the reader as a way of acquiring an overview of the design process, by which it is possible to see how a particular design variable may affect the performance outcome, or how various design variables together can contribute to the performance outcome. The chapter also serves as a synthesis of the previous chapters of the handbook. For example, the performance objectives presented in chapter 2 creates a lens through which the various design options presented in chapter 4 can be viewed. Moreover, the context factors presented in chapter 3 complements the relationships between the design options and the performance objectives, by highlighting important preconditions of the production system which may affect the relationship.

Most of the discussion up to this point has revolved around materials preparation design, context and performance on a generic and abstract level, in order to keep the guidelines applicable to many types of different contexts. However, the next chapter will provide the reader with a set of hands-on and practical examples which will bring the discussion down in to a practical way of applying the guidelines presented in the previous chapters.

6. Examples of materials preparation design

The companies which have been a part of the research project have conducted their own projects involving design of their materials preparation processes, as a separate track from the research studies.

This section presents a number of cases that the project companies have contributed with, often involving improving the design due to some specific issue encountered.

The section also presents summaries of a few of the research studies, highlighting important results that also can provide guidance when reviewed. All design cases and study cases have been adopted to fit on single page.

The cases presented in this section are summarised briefly below.

● **Design case 1: Fishbone localisation**
This case illustrates how the materials preparation location can be integrated in the overall design of the materials supply system. The solution revolves around the idea of aligning the materials flow perpendicularly to the assembly process—resulting in a fishbone pattern—allowing all materials preparation to be performed next-to-assembly.

● **Design case 2: An alternative to order batching**
This design case illustrates how a travelling kit concept can be used to increase the time-efficiency in a materials preparation process, while retaining a single-kit policy. The case is an interesting example of how the solution for attaining efficiency might not lie in choice of the process design as it is, but rather that the context of the design can be adapted instead.

● **Design case 3: The constant carrier**
This case illustrate how the picking package carrier can be designed to function effectively throughout all stages in the materials flow—from materials preparation to pre-assembly to final assembly.

● **Design case 4: Rack-integrated lift supports**
This design case illustrated how lift supports can integrated in the design of the storage racks. The solution relies on one part standardised storage rack design and another part of modularised attachments that allows a lift support to be attached if needed.

● **Design case 5: Semi-automatic pallet sliders**
This design case highlight important learnings regarding the pros and cons of using manual and semi-automatic pallet sliders. The case also provide some insight on the usefulness of pallet sliders in situations when boxes is not possible to use, due to, for example, the large size of the parts.

● **Design case 6: Let there be light**
This design case illustrates the experiences from implementing a pick-by-light system in the materials preparation process instead of a paper pick list. The case highlights important learnings which the company got from the implementation and shows the experienced effects on the performance of the process.

● **Design case 7: Demand classification one step further**
This design case illustrates how demand classification can be used to reduce the size of the preparation area, by treating component variants with different demand classification differently in terms of dedicated picking locations and storage packaging type. The example at the same time provides a way to make the preparation area possible to locate close to the assembly process, even if there is limited floor space there.

● **Design case 8: Pick-by-name**
This case illustrates a solution for improving the picking information system by means of the information structure, instead of changing the information medium and confirmation function. This case provides an interesting example of the picking information system can improved by means of visual management instead of upgrading the hardware.

● **Study example A: Picking information systems, batch-size and preparation errors**
This study example highlight the results from an experiment in regard to the quality outcome, where four picking information systems where compared in a kit preparation process.
Two findings are particularly important.
❶ One, a single-order policy generally result in fewer errors due to there being only one placement location and hence no mistake of making placement errors.
❷ Two, RFID armbands, that scans RFID tags at the locations automatically, holds a potential to improve quality in materials preparation over other methods, although speech-confirmations also show a good potential for ensuring quality.

● **Study example B: Picking information systems, batch-size and time-efficiency**
This study example highlight the results from an experiment in regard to time efficiency, where four picking information system where compared in a kit preparation process.
Two findings are particularly important.
❶ One, a single-order policy may as efficient, if not more efficient, than a batch order policy when confirmations are used to confirm activities.
❷ Two, in dense picking area, time efficiency is dependent on the design of the confirmation function, where pick-by-list with batch policy, using only a single confirmation for all placements, was superior to all other system in terms of efficiency.

The design cases and study examples are presented in full in the remining parts of this chapter.

6.1. Design case 1: Fishbone localisation

The Volvo Group Trucks final assembly plant in Tuve experienced traffic issues, late deliveries and large buffers areas in their materials supply system, and came up with a new way of organising the materials flow. The solution bears a remarkable resemblance to the Ishikawa problem solving tool—a fishbone.

As is common in many materials supply systems, the materials preparation at Volvo Group Truck's final assembly was located in separate "islands" within the plant, some even located externally. This led to long transportation distances of prepared materials. As a result, the plant experienced traffic issues with the tugger trains, leading to late deliveries and over handling of picking carts, in addition having many carts en route between preparation and assembly, and having many buffer areas. Consequently, the availability of line side materials was low and the cost of train drivers was substantial. The distances to the preparation areas also created a long response time when preparation errors were detected in assembly. An overview of the plant layout and the required routes is shown in figure 6.1.1.

… the availability of line side materials was low and the cost of train drivers was substantial

To improve the situation, the materials preparation designers decided to adopt a global layout for the materials supply system, organised in a "Fish bone" pattern. The new layout allows materials to flow in a straight line from the goods reception to kit preparation areas located next to and along the assembly process. Sequencing areas are still located separate from the assembly process, or externally for some flow, requiring tugger train transports, but are now located next to the goods receptions why the transport to the sequencing areas are next to eliminated. The new localisation have improved the availability of materials at the line side, improved the response time for resolving preparation errors detected in assembly, and reduced the lead time substantially by removing buffers. Further, the change of localisation have reduced the amount of logistics traffic within the plant, thereby markedly improving the safety, as well as enabled job balancing between kit preparation and assembly work tasks for the. The fishbone localisation is shown in figure 6.2.2.

Some low runner parts was however not possible fit in the kit preparation processes, due to floor space restrictions. The next step is hence to find an optimal solution for how to manage the low runner parts as well.

Figure 6.1.1. Materials preparation spread out inside and outside the facility (before). Arrows indicate different material flows.

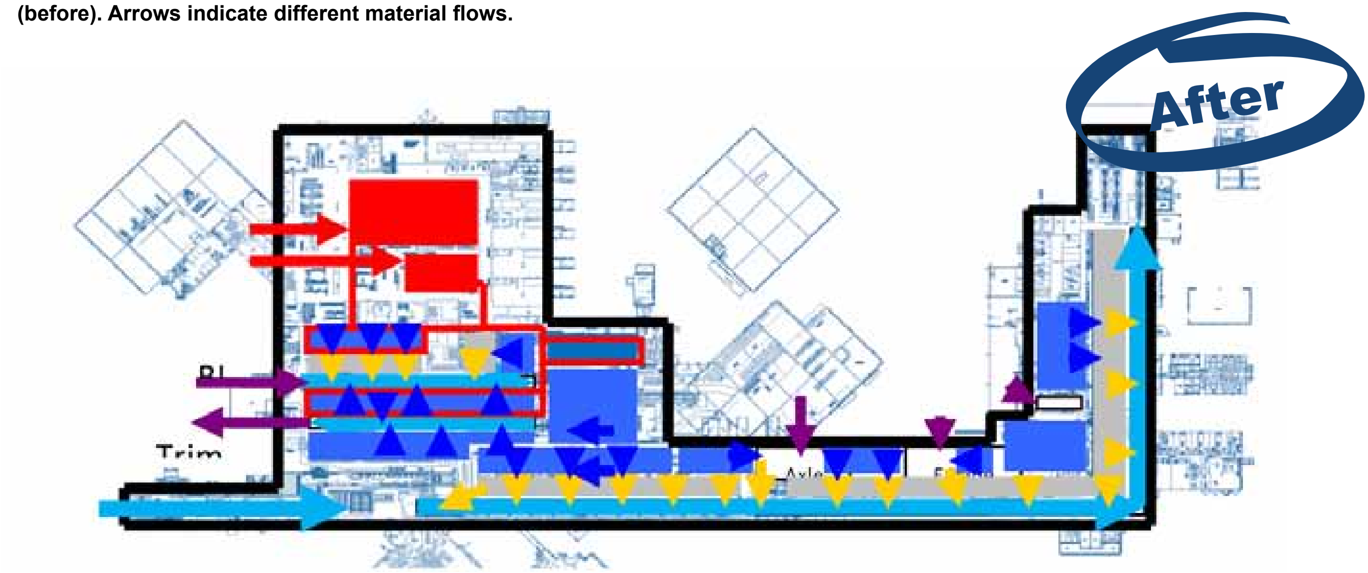

Figure 6.1.2. Kit preparation localised next to the assembly process and centralised sequencing (after). Arrows indicate different material flows

6.2. Design case 2: An alternative to order batching

Volvo used to have at least one kit per assembly station, necessary for managing the high diversity products. Kits were prepared in batches as large as possible to improve time efficiency of kit preparation. However, the large number of different kits created crowded assembly processs, where an alternative perspective offered the solution: the travelling kit.

Figure 6.2.2: The larger travelling kit

Truck assembly is renowned for the high diversity of end-products, leading to a myriad component variants to manage. Volvo is no stranger to this issue, why at least one stationary kit was used at each assembly station. The kits were prepared in batches, made as large as possible given the size constraints of the kit carrier design. This lead to very many different kit carrier designs to manage, which had low flexibility to manage changes in the production system. For example, the kit carriers design and the kit contents had to be reviewed every time the takt changed in the production system, leading to costly and stressful design changes of the kit. The very many different kits also resulted in numerous small kit preparation areas. For some kits, there were very few components per kit which led to a low time efficiency in the kit preparation process as a whole. Further, due to the being stationary at the border of line, the assemblers still had to walk to the materials facade to pick the parts – a distance that varied due to the moving assembly process. Preparation errors were also fairly common in the kits, leading to costly corrections having to be made.

The very many different kits also resulted in numerous small kit preparation areas.

Travelling kits were introduced, attached to the assembly object and follows along for multiple assembly stations, being used by multiple assemblers. All travel kits are placed as close as possible to the point where the components are assembled, thereby minimising the walking distance for the assembler. All kits are now also prepared one kit at a time, one assembly object at a time. This way, several of the previous kit preparation areas are merged into one, thereby improving floor space efficiency and simplifies replenishment to the preparation areas by the materials handling system. The time efficiency compared to the previous batching policy is also maintained due to more parts being picked for each kit. Rebalancing is too made simpler, as there are fewer kit carriers and kits to redesign upon for example changes in takt, although the new kit carriers are less flexible in regard to ECOs. The redesign of a single kit carrier also requires more effort than redesigning a single carrier previously. The single kit policy has also improved the kit quality as the possibility of misplacing a component in the wrong kit is removed.

During the implementation, there were a few instances when kit carrier, either due to the design or due to the position at the assembly process, created unnecessary movements, increased the picking time or created a distrubance for the assemblers. These issues has since been remidied and the next step is to transfer the concept of the travelling kit to other factories and to continue to improve the deisgn for improved ergonmics and quality.

Figure 6.2.1: Many kit carriers all along the assembly process (before)

Figure 6.2.3: The travelling kit used at the assembly process. Yellow arrows indice the truck onto which the components are assembled.

6.3. Design case 3: The constant carrier

A common creed in materials preparation design is that “what happens in the materials preparation process, stays in the materials preparation process”. However, as this case example from Volvo GTO shows, there may be opportunities to improve the whole materials flow from goods reception, through preparation and to assembly by looking beyond this creed through considering the design of the carrier of the prepared materials.

Kitting was used in the final assembly plants of Volvo GTO in order to manage the floor-space restrictions near the assembly process. At the outset, the kit preparation was performed as one step in a “silo” designed materials flow, beginning from goods reception to warehouse, then onwards to preparation and pre-assembly before reaching the final assembly. For many material flows, this approach meant that heavy parts had to be handled up to four times before reaching the assembly, in addition to an accumulation of inventory as buffers arose between each step, leading to long lead times and large floor space requirements. At the kit preparation area, up to three kits were prepared in one batch, why there were often many carriers for the prepared materials present at once, leading to the carriers being loaded in the wrong order, or the order of the carriers lost as the prepared materials was collected at the preparation area .

To remove the many handling steps of the silo approach, a one piece flow approach was implemented instead, based around the carrier of the prepared materials. The solution meant that a single carrier was used in all of the steps, beginning with being loaded already in the warehouse, then passing onto the kit preparation area, where the different parts required in the pre- and final assembly steps were loaded onto the carrier, where after the same carrier passed onto pre- and final assembly. The one piece flow approach is shown in figure 6.3.2.

The one piece flow approach meant that the heavy parts only had to be lifted once in the entire materials flow (at the kit preparation area) while also reducing the buffer sizes substantially and per extension the global lead time. While the new approach meant that the carrier was significantly more expensive, it allowed the kit preparation, pre-assembly areas to be moved closer to the assembly process, thereby enabling the prepared materials to be delivered manually to assembly at a reduced logistics delivery cost while providing the opportunity to balance preparation and assembly tasks. However, in factories where there are more than one final assembly processs, only one can be supplied manually. The next step is to introduce the one piece flow solution in all factories.

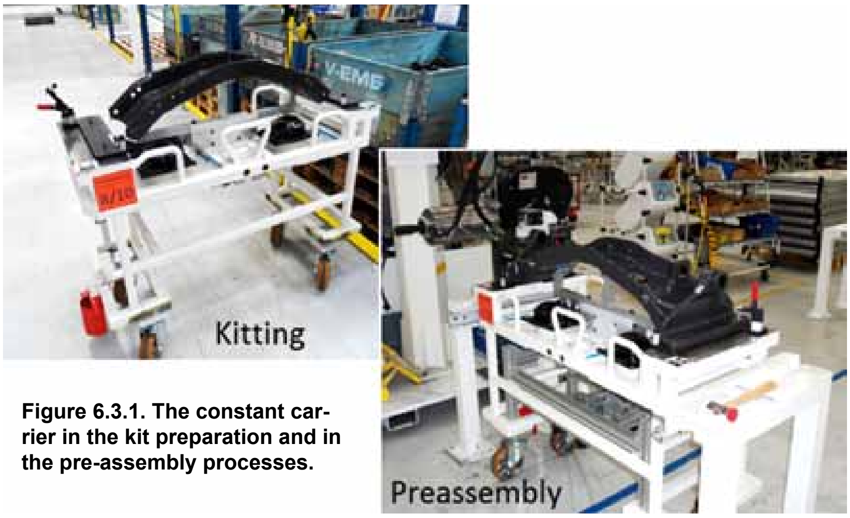

Figure 6.3.1. The constant carrier in the kit preparation and in the pre-assembly processes.

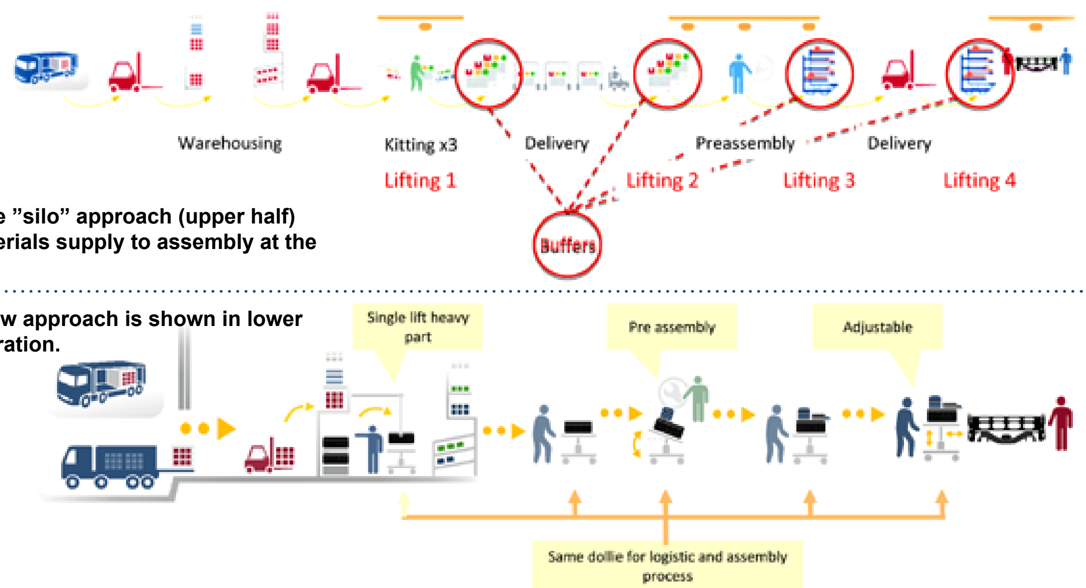

Figure 6.3.2. The ”silo” approach (upper half) used in the materials supply to assembly at the outset.

The one pice flow approach is shown in lower half of the illustration.

6.4. Design Case 4: Rack-integrated lift support

When the preparation areas at Scania were first constructed, each process was designed uniquely based on the requirements for that process. For lifting support, expensive and inflexible multi-post lifts were installed in those processes where heavy parts were picked. When reconstructing the process based on a unison design standard, the lift supports were instead integrated into the design of the storage shelves.

To customise each process to uniquely fit the requirements for each materials preparation process may seem as the the approach to go for. This is what was done at Scanie when they constructed their materials preparation processes some time ago. For those processes where heavy parts were managed, multi-post lifts were installed for supporting the pickers when picking the heavy parts. Although bringing the pickers the neccessary support for performing the materials preparation work, the lifts were very expensive to procure. In addition to the individual process being inflexible to changing requirements, due to the highly customised designs, the use of the multi-post lifts further diminished the flexbility for being able to change the process designs effectively. Further, the use of the multi-post lifts prevented the space above the pick-locations from being used for storage and the floor area where the posts connect to the floor for pick-locations.

During a redesign based on unison design standard, the lifts were made part of the shelf design as a modular option where needed. The solution exploited the standardised aisle width by adding steal beams across the aisle. Since the beams are attached to the shelves from inside of the aisle, there is room for storage above the pick-locations and, as there are no posts connected to the floor, the shelf space previously occupied by the posts can now be used as pick-locations. Further, the steal beams can be attached at any height, thereby allowing for height adjustments of the lifting support. An additional benefit is that the beams can be used for attaching lights to, instead of being supended from the facility ceiling. Now it is also much simpler to rebalance preparation tasks between process due to the standardised design.

> ***The solution exploited the standardised aisle width by adding steal beams across the aisle.***

In summary, the outcome of integrating the lift support in the design compared to the preiovus highly customised design resulted in:

+ Little effort for adjusting the height of the lift support for imporved erognomics
+ Picking locations above the pick-locations
+ Substantially lower cost for the steel in the lift support setups
+ Floor- and shelf-space efficiency
+ Lights attached to the beams gives much better lighting of the picking area
- Pallet trestles (supports placed under pallets to raise the pallet to better picking height) cannot be used.

Figure 6.4.1: Multi-post lifts and customised design (before)

Figure 6.4.2: Standardised aisle width and beams for attaching lift supports (after)

6.5. Design Case 5: Semi-automatic pallet sliders

Pallet sliders, that is, railings which suspends a pallet and allows it to be pulled out into the picking aisle, has been used for a long time at Scania to improve the space efficiency in materials preparation processes where the storage packaging is mainly pallets. More recently, improved manual solutions for pallet sliders, as well as electric and pneumatic solutions, have been evaluated and introduced, resulting in the experiences presented herein.

A way to manage the space requirements for materials stored in pallets has been to use pallet sliders

Figure 6.5.1: Manual pallet slider for 70% exposure (before)

Although the type of storage packaging used in the materials preparation process has a major impact on the performance, it is often the case that the choice of storage packaging is a consequence of the component characteristics than an actual decision to be made by the materials preparation designer. At Scania, many of the components are large and thereby necessitate storage in pallets. A way to manage the space requirements for materials stored in pallets has been to use pallet sliders – i.e. railings in the shelf which suspends the pallet and allows it to be pulled out into the aisle when materials are needed – which allows for much denser picking areas to be designed.

Previously, two types of pallet sliders were used for all component types – regardless of weight. One version allowed 50% of the pallet length to be pulled into the aisle, while the second allowed for 70%. Both versions allowed for the materials to be accessed from the long side of the pallet, which brought an improved picking posture. However, the heavier pallets required a substantial effort for being pulled into the aisle, resulting in an ergonomically unsound situation.

To improve the ergonomics for handling the pallets, two new types of sliders are used today, where the one used for a particular component variant is determined by the weight of the pallet. For weights below 400 kg, a manual solution is used, which allows the pallet to be pulled out 100%. For weights above 400 kg, an electrically powered slider is used, which also allows for 100% of the pallet length to be pulled out into the aisle. The main benefits from the new solutions, besides removing the heavy pulls by using electric sliders for weights above 400 kg, is that the materials within the pallets can be accessed from anywhere on the long side when pulled out completely. Further, lift supports can reach anywhere within the pallet, thereby avoiding any unsound lifting postures and making it easy to make use of the lifting supports. Scania have also tested pneumatically powered sliders, which have the same cost as electrically powered, but have identified safety concerns from the air pressure that builds up during opening/closing.

In summary, the experiences from the new solutions for pallet sliders can be summarised as follows:

+ Possibility to use electrically powered sliders for higher pallet weights improves ergonomics
+ Improved access to materials from being able to expose 100% of the pallets
- Manual sliders that can be pulled out 100% has somewhat higher procurement cost than the 50%/75% versions
- Electrically powered have higher procurement cost than manual.

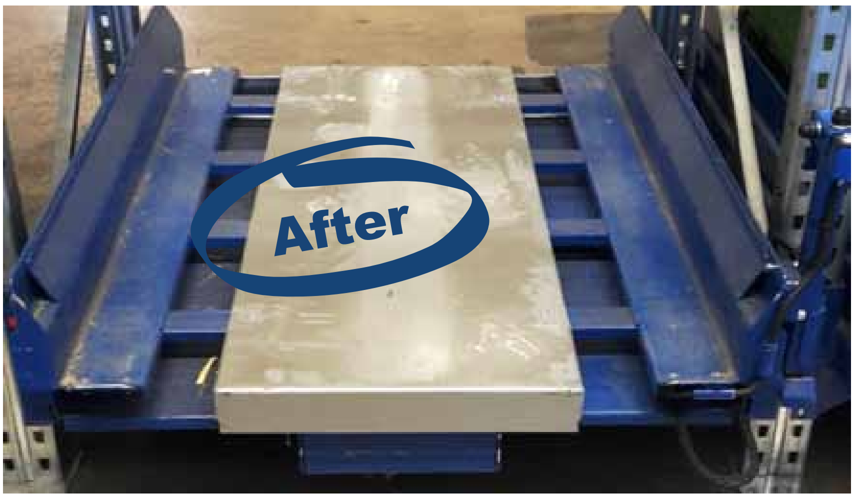

Figure 6.5.2: Electrically powered pallet slider (after)

6.6. Design case 6: Let there be light

How much of an advance it really is to go from the traditional paper pick-list to more advanced technology for picking information has been discussed vehemently both in practice and in academia, without reaching a uniform conclusion. Here, Volvo GTO provides an example that builds the case for the more advanced technology route.

When the picking information system used at Volvo GTO was the paper-pick list, the information system marked its presence in the plant by numerous printers and papers around the shop-floor, se figure 6.6.1. Kit preparation was at this time a very costly activity, only used when there were severe space restrictions at the assembly process.

The picking accuracy was at this time very low, leading to many picking errors that had to be resolved at the assembly process. A measure to improve the kit preparation performance was taken, where the paper pick-lists were replaced by pick-by-light systems in the kit preparation processes. The use of pick-by-light meant that once the operator initiated the picking tour by the press of a button, the IT-system managed all the information that needed presentation by the pick-by-light modules placed at the picking locations. The new system also prevented the picking tour to proceed until the light indicator for the current pick-activity had been confirmed, by pressing the button on the pick-by-light module being pressed.

The change from a paper pick-list to pick-by-light resulted in several improvements

The installed pick-by-light system is shown in picture 6.6.2. The change from a paper pick-list to pick-by-light resulted in several improvements:

- About half the time to complete a picking tour
- Improved quality from 200 to 20 PPM
- Reduced learning time for newly hires
- Kit preparation could be used on a larger scale, improving overall quality and man-hour efficiency

However, given the numerous pick-by-light modules that had to be procured and installed, the investment cost was substantial. There was also a fairly long calibration time period until the system functioned as was desired. Another adverse consequence from pick-by-light is that the kit preparation areas now are less flexible, due to the cables mounted on the storage racks to supply the pick-by-light modules with electricity and signal.

The new system was found less effective in processes with few component variants, as the cost and reduced flexibility in such simpler picking scenarios outweighed the small improvements in time-efficiency and quality that was achieved.

Additionally, the new system was less effective in huge picking areas with many and large component variants, as the visibility of the lit lights was not enough there. The next step is to refine the implemented solution by reducing the installation cost, improving the flexibility and thereby make the whole solution more robust.

Figure 6.6.1. The paper pick-list used before the pick-by-light system was introduced (left side). A close-up view of the pick-by-light system (right side). The display above the storage bin shows what to pick. The white button to the right is pressed to confirm the pick.

Figure 6.6.2. An overview of a kit preparation aisle where the pick-by-light system has been installed.

6.7. Design example: Demand classification one step further

Presenting a component variant at the preparation area requires space in form of a picking location floor space. When there are numerous component variants, the preparation area risks becoming large, leading to long distances to walk during picking which results in low efficiency. This example illustrates a way of managing a large range of component variants, by means of utilizing frequency classification to select picking location and storage packaging for the variants being managed.

… many of the component variants in need of presentation were only rarely picked due to being low-runner variants (or "shelf-warmers")

At Volvo Group Trucks, there are numerous component variants in need of handling in the materials preparation processes. But keeping all on display at once is not really an option, as the preparation areas would become too large, leading to inefficient picking and requiring a lot of floor space. However, many of the component variants in need of presentation were only rarely picked due to being low-runner variants (or "shelf-warmers").

Instead of keeping all variants on display at all times, the variants categorized in three classes based on the consumption rate. After distribution analysis, the 20% of part numbers that made up 70% of the total demand were classified as high-runners; the 30% of the remaining part that made up the next 25% of total demand were classified as medium-runners, while the last 50% of part numbers that made up the remaining 5% of demand were classified were the "shelf-warmers".

All high-runner variants were given a dedicated and fixed picking location at the preparation area, presented in the same packaging as previously.

All the medium-runners were also given a dedicated and fixed picking location, but their storage packaging was set be downsized in a preceding step, so that they required a smaller storage space at the preparation area.

The low-runners are kept in a floating section at the preparation areas, having no dedicated of fixed picking location, but are instead retrieved from storage when needed.

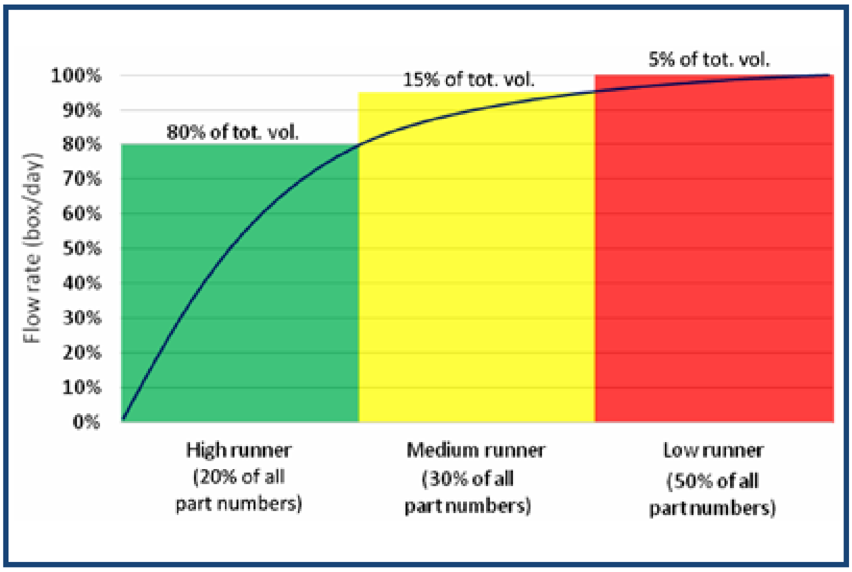

Figure 6.7.1. After plotting the forecasted box consumption (from highest to lowest), we can apply a distribution analysis to the data curve to identify high, medium and low running supermarket boxes.
The highest volume part numbers which account for the highest percentage of the total forecasted box volume are determined to be "high volume".
The next highest volume part numbers, making up the middle range of the total forecasted box volume are considered "medium volume".
The lowest volume part numbers, making up a small percentage of the total forecasted box volume are considered "low volume".

The effects from applying this categorization among the component variants were substantially smaller preparation that allowed for more efficient picking, as the walking distances became less. Expressed in numbers, the 20% of component variants classified as high-runners occupies approximately 70% of the floor space at the preparation area; while the remaining 30% of variants classified as either medium- or low-runners occupies only 30% of the floor-space at the preparation area.

One drawback of using this principle, is that the classification has to be updated over time, which is usually performed once every 3 months or during larger changes in the system, for example in preparation for the launch of a new product model. Another drawback is that the classification can lead to increased amounts of materials handling, although this effect is possible to almost remove with proper balancing and planning.

This solution is appropriate when the preparation is located close to the assembly, or to make it possible to locate the process close to the assembly process. However, the solution requires a detailed data-set of the variants in terms of their demand. The next step is to improve the planning system and ideally automate the classification procedure, for being able to perform the classification with less effort and more frequently.

6.8. Design case 8: Pick-by-name

Science dictates that the human mind is only capable of keeping 4 digits at once in the short-term memory. In this way, order pickers are often exposed to inhuman conditions when they are tasked to remember a whole component variant in order to pick the correct part. Add to that the issue of many component variants being highly similar, with only minor differences between adjacent component variants, and you have a recipe for picking errors. This example from Scania shows how handle this situation, by providing the recipe for soup instead, where ”soup” could be what is actually supposed to be picked.

The traditional format of using the component variants as the identification parameter in storage resulted in many picking location identifiers looking very similar

The pick-list on paper was used as picking information system in Scania’s materials preparation design policy. The traditional format of using the component variants as the identification parameter in storage resulted in many picking location identifiers looking very similar, with only two digits in the reverse order in some instances, for example 0201 instead of 0102, leading to a low picking accuracy as operators mistook the one part for the other. The similarity between component variants combined with using no pick- or place confirmation further exasperated the pick-error levels. A new standard for denoting the picking locations was introduced to deal with the problem.

First, each shelf section was given a two-digit numerical identifier, where one side of the aisle displayed odd numbers and the other side displayed even numbers.

Then, within each section, each picking location was given a symbolic name, so that the picking location identifier on pick-list showed the section and the symbolic name for the location.

Also, to further reduce the risk of mistaking one component variant for another, a rule of making all component variant names within the same section essentially different was used. For example, never ”24 – OX” and ”24-CALF”, but ”24 – OX” and ”24 – SHOE”.

While the use of names instead of numbers meant a slight increase in administration effort when designing new processes or when changing or adding component variants at the process, the change did significantly increase the picking accuracy. Another unexpected benefit was that the learning times for new hires also was reduced.

Figure 6.8.2. The new picking location identifiers where names are used to denote the picking locations. Compared to the old system, the new system has improved the picking accuracy and reduced the learning times for new hires, at the cost of slight increase in administration time.

Figure 6.8.1. The old denotation of picking locations with the component variant used as picking location identifier. As can be seen in the picture, the denotations in the same storage section are very similar, making it easy to mistake one part for another.

6.9. Study example A: Picking information systems, batch-size and preparation errors

When it comes to selecting which batching policy to use, an important concern is the quality outcome that can be expected, in addition to which picking information to use in the given batching policy. In an experiment performed in the project, four types of picking information systems were compared in two batching policies in regards to the quality outcome, measured in amount of picking errors. This example presents the results from that experiment.

Marking a paper pick list with a pen, pushing buttons or confirming picks with speech commands are all common solutions found in industry for confirming picking activities. Also, new solutions are emerging, for example scanning RFID-tags with a bracelet worn on the arm.

Two key questions for the materials preparation designer in this area is: which type of system provides the highest quality outcome, given the process settings? Also, is there a difference between picking to a single package and a batch?

To answer these questions, an experiment was organised within the research project, with the aim to compare the performance of four types of picking information systems: pick-by-list (pick list on paper, mark order line with pen to confirm task), pick-by-light (a light lights up at pick location, confirm with button press), pick-by-voice (pick location from voice in headset, confirm with speech), and pick-by-vision (pick location from smart-glass, confirm by scanning RFID-tag with RFID-reading arm band).

A kit preparation process was designed in a laboratory to simulate a high-performing kit preparation process typical for automotive production. The work area consisted of a single picking aisle, seven metres long, with shelves on both sides. The picker walked in a U-pattern in the picking aisle, picking from the left side, with a movable kit carrier with either one or four kits.

The shelves on one side of the aisle presented the materials in 780-boxes on three shelf levels (the short side of the box towards the aisle; 45 pick locations in total), while the shelves on the other side presented the materials in 840-boxes on two shelf levels (the long side of the box towards the picker ; 16 pick-locations in total).

To complete 1 picking tour, the picker had to collect 15 components (specified by the pick information) for each kit on the trolley. The four picking information systems were tested when picking to either one kit or four kits during the same picking tour. When picking to 1 kits, the pick-by-light, pick-by-voice and pick-by-vision systems had to also confirm the placement in the kit.

Five pickers were recruited, who completed ten picking tours with each combination of picking information system and batch-size (one or four kits per tour).

Figure A1 shows the amount of picking errors for the four picking information systems in the batch-kit policy (no error occurred in the single-kit policy).

The results are shown in Figure A1 and the conclusions are summarised in the points below:

- No errors occurred in the single-kit policy, which is an interesting result on its own. This result indicate that a single-kit policy can be advantageous over a batch-kit policy for the quality outcome.
- Using a batch-kit policy introduces the risk of making placement errors, which was the only error type that occurred for each of the four picking information systems. Confirming placements effectively is hence crucial for the quality outcome with a batch-kit policy.
- Using a batch-kit policy increases the complexity of the picking information, necessitates placement confirmation and overall increases the investment cost due to the more advanced picking information system setup required.
- Pick-by-list, which was the only system without a feedback mechanism for the pick- and placement confirmations, resulted in the most amount of errors. This result indicate that the feedback mechanism provided by more advanced systems indeed is important for the quality outcome.
- In conclusion, the experiment indicates that both the choice of batching policy and the choice of picking information system impact the quality of outcome of the materials preparation process.

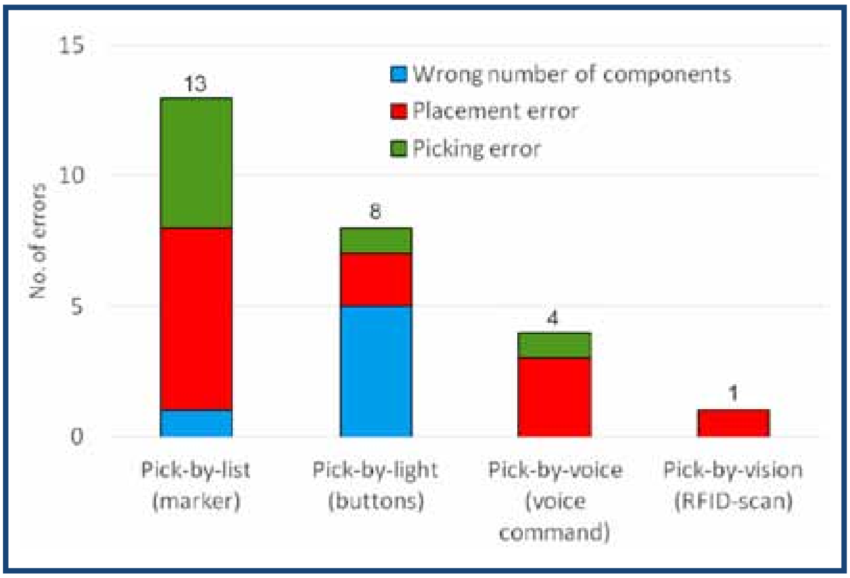

Figure A1: The number of observed errors when four different types of picking information systems were applied in an experimental application of batch preparation of kits. No errors were observed when the same four systems were applied with a single-kit policy. The confirmation method applied with each system is shown within parantheses.

6.10. Study example B: Picking information systems, batch-size and time-efficiency

There are many different types of picking information systems available and to select a system which is effective for the preparation process is essential. In an experiment performed in the project, four types of picking information systems were compared in regards to picking time. This example presents the results from that experiment.

The paper pick list, pick-by-light systems and pick-by-voice systems are all common systems found in industry for guiding picking processes. Also, new systems are emerging, for example pick-by-vision systems where the picker gets picking information from smart-glasses. The key question for the materials preparation designer in this area is: which type of system is the more efficient, given the process settings?

To answer this question, an experiment was organised within the research project, with the aim to compare the performance of four types of picking information systems: pick-by-list (pick list on paper, mark order line with pen to confirm task), pick-by-light (a light lights up at pick location, confirm with button press), pick-by-voice (pick location from voice in headset, confirm with speech), and pick-by-vision (pick location from smart-glass, confirm by scanning RFID-tag with RFID-reading arm band).

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… the efficiency of a larger batch-size over picking to one kit per tour is reduced or even reversed when the placements have to be confirmed.

To complete one picking tour, the picker had to collect 15 components (specified by the pick information) for each kit on the trolley. The four picking information systems were tested when picking to either one kit or four kits during the same picking tour. When picking to four kits, the pick-by-light, pick-by-voice and pick-by-vision systems had to also confirm the placement in the kit.

Five pickers were recruited, who completed ten picking tours with each combination of picking information system and batch-size (one or four kits per tour). Figure B1 shows the average time per picked component and the 95% confidence interval for the four picking information systems over the two batch sizes (Batch [-1] = 1 kit ; Batch [+1] = 4 kits).

The results in Figure B1 shows that when picking to one kit, pick-by-light was the most efficient system and that pick-by-vision and pick-by-list are indistinguishable. When picking to four kits during the same tour however, the pick-by-list was the most efficient system, followed by pick-by-light and pick-by-vision. Pick-by-voice performed the least efficient in either batch-size, due to a dense picking environment being studied, thus little time between picks to handle voice-based information.

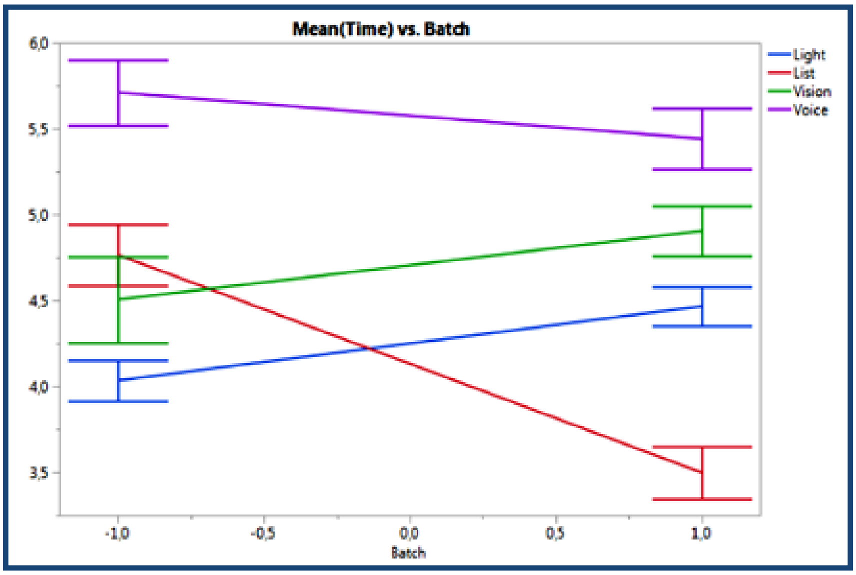

Figure B1. The relationships between time-efficiency and batch-size for 4 different picking informaition systems, that was identified in a reasearch experiment. The unit on the y-axis is seconds per picked part and the brackets at the ends show the 95% CI.

Apart from a ranking between the system types over the two batch-sizes, the experiment also showed that the efficiency of a larger batch-size over picking to one kit per tour is reduced or even reversed (see pick-by-light and pick-by-vision graphs in Figure B1) due when the placements have to be confirmed. When placements are not confirmed, as was the case for the pick-by-list system, a larger batch-size is clearly more efficient.

The pick error analysis showed that pick-by-list system produced the most amount of errors (18 errors in total, compared to nine errors for pick-by-light, five errors for pick-by-voice and zero errors for pick-by-vision). The observed errors occured due to wrong placements when a four kit batch-size was used. No errors occured when the batch size was one kit.

Summary of chapter 6
Examples of materials preparation design

This chapter has presented 10 cases of materials preparation design. The cases demonstrate various problems and solutions related to materials preparation design, and cover most of the design variables brought up earlier in the book.

In design case 1, a somewhat unconventional factory localisation of the materials preparation relative to the assembly line was discussed. The layout can be likened to a ”fishbone” where all materials flow in a perpendicular direction towards the assembly line, all the way from the goods reception. By implementing this layout, it was possible to resolve forklift traffic congestion issues within the facility and several additional benefits were realised.

Design case 2 highlighted a change from a stationary to a travelling kit concept. After the change, each kit became larger and more components were kitted during the same picking tour. Moreover, a single kit policy could be applied. The changes led to maintained efficiency at the picking area, while at the same time greatly improving the volume flexibility.

In design case 3, the kit carrier was designed so that it could be used in all steps from the goods reception, trough the materials preparation and pre-assembly, all the way to the assembly process. The example demonstrates how a holistic view of the materials preparation with respect to the materials flow can eliminate wastes on a system level.

An approach for integrating the lifting support in the shelves at the preparation area was discussed in design case 4. The example illustrates how rather small means of technical innovation can create substantial gains in space-efficiency, cost-efficiency as well improved opportunities for lighting at the preparation area.

With design case 5, the use of electric pallet sliders is discussed. When the sliders were implemented in the case, the ease by which heavy pallets could be handled greatly improved, which in many ways motivated the rather high investment costs.

In design case 6, the effects of introducing a pick-by-light system instead of a paper pick list were highlighted. Apart from a substantial productivity increase during the picking tour, the pick-by-light system also increased the quality levels from 200 ppm to about 20 ppm.

A way to simplify the range of component variants by means of frequency classification was discussed in design case 7. The approach would be applicable in most settings that have a wide range of products. As shown by the example, a proper categorisation can make it possible to design more compact preparation areas, which can bring improved productivity, flexibility and quality levels.

In design case 8, a change from presenting component variants by means of their part number to presentation by means of symbolic names is discussed. The case illustrates that rather simple, but clever, modifications of the picking information can lead to substantial improvements in both picking quality and efficiency.

In study example A, the relationship between the batch size and the type of picking information system with respect to the quality outcome is discussed. Here, results from an experiment shows that using a single-kit policy can substantially reduce the amount of errors during kit preparation, as there is no risk of making placement errors.

Finally, in study example B, the impact on time-efficiency from various types of picking information systems and batching policies are discussed on basis of an experiment. The experiment results indicate that using placement confirmations to support quality can negatively affect the productivity, thereby highlighting an important trade-off. Moreover, indications of various types of picking information systems affect quality are shown.

The chapter as a whole presents a set of practical applications of materials preparation design that may be used as an inspiration and a source of practical ideas. Moreover, the chapter provides a practice-based round off to the more generic advice about materials preparation design earlier in the book.

7. Conclusions

This book has dealt with materials preparation design in mixed-model assembly systems.

Throughout the book, guidelines for how to design materials preparation processes to achieve desired performance levels with respect to the context have been outlined and various design options have been discussed.

The guidelines are based industrial knowledge and experience, as well as on previous research about materials preparation, and were formulated to be applicable by academics and practitioners dealing with the design of processes for materials preparation.

The framework presented in the book can be useful when plans for new processes are formulated, or when it is desirable to improve already existing applications.

As was described in the first chapter, materials preparation effectively arranges materials in accordance with the requirements of the customer process. The need for materials preparation is increasing in industry due to increased application of, for example, kitting and part-sequencing, which are beneficial compared to other modes of materials supply when there is multitude of component variants. The process by which materials preparation is carried out can be designed in many ways and there are many decisions needed to be made when a design is chosen. The premise of the framework presented in this book is that design decisions affect the performance levels of the process, and different decisions may be more beneficial in some contexts than others.

The guidelines are based industrial knowledge and experience, as well as on previous research about materials preparation

The scope of the book was materials preparation that primarily involves manual labour, where a single worker completes the whole delivery. The book started with the assumptions that the set of component variants for which the process should be designed had already been selected, and that the type of material preparation had been decided. With these assumptions in place, the discussion carried out in the book could focus on how the organisation, the infrastructure, and the information could be chosen to support the desired performance outcomes, with respect to the context.

The design, the performance, and the context were the three main parts of the framework presented in the book. These parts were divided into different variables, which were further subdivided into different aspects. In the earlier parts of the book (chapters 2, 3 and 4), the various variables and aspects related to the design, context and performance were defined and explained. In the latter part of the book (chapters 5 and 6), the aspects were brought together and viewed from a holistic viewpoint and the relations between the design, context and performance were explored. As a whole, the book provides the reader with both an overview of how the materials preparation design can be chosen, all the while providing ample opportunity to study particular aspects of the design in a detailed fashion.

The idea is that the reader may use the guidelines as a starting point and then make sensible adaptations of the guidelines to the own particular context

Much of the discussion about materials preparation design carried out in the book was kept on a general level for the guidelines to fit with a wide variety of contexts. The idea is that the reader may use the guidelines as a starting point and then make sensible adaptations of the guidelines to the own particular context. However, with the industrial examples presented in chapter 6, the reader is provided with hands-on examples of what the decisions about materials preparation design may look like, and how the guidelines may be applied.

While the book set out to deal with materials preparation design in a comprehensive way, the book should not be seen as to include every relevant option and aspect imaginable. In industry, there is a theoretically infinite variety of settings and opportunities when it comes to materials preparation design. What this book provides is a structure for organising the design process, along with examples of different decisions that may be applicable. Outside the book's scope, there are several additional opportunities in form of, for example, robotics, autonomous vehicles and warehouse management systems that may support the materials preparation in an efficient way. While such options are not covered in the current book, these too should be considered before the final choice of design is made.

Materials preparation design represents an evolving body of knowledge. This evolution is spurred on by researchers from many parts of the world whom, with different approaches, strive to understand the complex relations within logistics and production systems. These relations consist of factors related to people, technology, information and organisations, and it would be safe to say that the development of knowledge will never fully reach a state of completion. There is also a multitude of current trends and developments within industry that in many ways may fundamentally change the prerequisites for how operations management related to logistics and production systems is conducted. Examples of these trends include many of the initiatives associated with industry 4.0, in terms Internet-of-Things, augmented- and virtual reality, as well as new manufacturing approaches such as 3D-printing. It is impossible to say at the current time how such developments will change the landscape of design for logistics and production systems, and there is a shared responsibility by industry and academia to keep striving to understand the possibilities, as well as the challenges, that these developments will bring. One thing can, however, be said with a bit more certainty, and that is that there will always be a need for design.

The design, the performance, and the context were the three main parts of the framework presented in the book

Index

Materials preparation handbook
Guidelines for choice of materials preparation design

Materials preparation is increasingly applied with mixed model assembly as means of support to the assembly process. With materials preparation, components are sorted at a picking area before reaching the assembly process. This is required when, for example, materials are supplied to the assembly process by kitting or part sequencing approaches. When presented to the assembler, prepared materials shorten the walking distance and simplifies the search for components in the assembly process compared to other approaches, and promotes the assembly's performance. However, to best support the assembly process, the materials preparation must be carried out cost effectively with satisfactory quality, flexibility, productivity, and ergonomics, with respect to the current context.

Previous research and practitioner experience has shown that the materials preparation design can greatly affect the performance outcome. There is a multitude of decisions involved with the choice of materials preparation design, and choosing an appropriate design that fulfils the performance expectations with respect to the context can be a complicated task. The aim of this handbook is to present previous research and practitioner knowledge regarding how to design materials preparation processes in assembly systems, and to consolidate the various decisions associated with materials preparation design into a framework that can be applied by practitioners and academics dealing with materials preparation design.

The handbook presents the various aspects related to the design, context and performance of materials preparation, in form of guidelines for how these aspects may be considered in the design process. The guidelines focus on how to design manual picking processes where a single worker carries out the picking work. The context in which the guidelines are presented is mixed model assembly, but much of the content would also find applicability in other contexts, for example warehouse order picking in distribution or e-commerce settings. The guidelines presented in the handbook are based on the outcome of a research project which was a joint venture between academia and industry, and included partners from both the manufacturing and distribution sectors.

This handbook is intended for readers interested about the design of picking systems. The book is written for readers from both academia, for example researchers or students, and from industry, for example engineers, managers or consultants. The book's structure permits easy access to referential reading about various aspects of the materials preparation design, and although the book certainly could be read from start to finish, it would serve the reader to start with a set of questions already in mind. Materials preparation is carried out for supporting the assembly process, and this book supports the decision process when choosing a materials preparation design

Patrik Fager

Patrik is a PhD student at the Department of Technology Management & Economics at Chalmers University of Technology.

He conducts research about production logistics, with a focus on materials handling and order picking applications in mixed-model assembly systems.

Department of Technology Management & Economics
Chalmers University of Technology