THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

In-plant materials supply: Supporting the choice between kitting and continuous supply

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Abstract

This thesis focuses on the two materials feeding principles of "kitting" and "continuous supply" within in-plant materials supply in mass customised assembly. With the principle of kitting, parts are delivered and presented to the assembly operations in pre-sorted kits, with each kit containing parts for one assembly object. With the principle of continuous supply, a number of parts of each part number are presented at the assembly station where they are to assembled, which means that when continuous supply is used in a mixed-model assembly context, where different assembly objects require different parts, the assembler at each assembly station needs to pick the right parts to assemble on each assembly object.

Depending on whether kitting or continuous supply is used, the performance of both in-plant materials supply and assembly can be affected. However, within industry, there is considerable confusion regarding which materials feeding principle should be used when. Moreover, the existing research literature on the topic is far from exhaustive. This thesis aims to provide knowledge of how the configuration and the context of the in-plant materials supply system should be considered when a choice between kitting and continuous supply is made.

The research has been conducted mainly in the form of case studies at assembly plants within the Swedish automotive industry. Complementing the case studies, one experiment has been conducted. In several of the studies, it has been possible to study both kitting and continuous supply in the same setting, which has resulted in an excellent basis for comparison between the two materials feeding principles. The other studies have instead focused on aspects within each of the two materials feeding principles, enabling an understanding of how each of the two materials feeding principles can be applied and of how this can affect performance.

The thesis provides a structured and thorough account of kitting and continuous supply and the effects of using these principles, depending on the configuration and the context of the in-plant materials supply system. This has previously been lacking. The structured and thorough account presented in the thesis contributes to an understanding of the benefits and drawbacks of kitting and continuous supply and the applicability of each of the materials feeding principles. The thesis further relates the choice between kitting and continuous supply to the design of an in-plant materials supply system as a whole and suggests an outline of such a design process.

Keywords: in-plant materials supply, materials feeding principles, kitting, continuous supply

List of papers included in the thesis

This thesis is based on the research presented in six papers. Each of these papers is included in full and presented after the cover paper.

Paper I

Hanson, R. and Brolin, A. (2012), "A comparison of kitting and continuous supply in in-plant materials supply". *International Journal of Production Research*, DOI:10.1080/00207543.2012.657806.

Paper II

Hanson, R. and Medbo, L. (2011), "Kitting and time efficiency in manual assembly". *International Journal of Production Research*, DOI:10.1080/00207543.2011.555786.

Paper III

Hanson, R., Medbo, L. and Medbo, P. (2012), "Assembly station design – a quantitative comparison of the effects of kitting and continuous supply". *Journal of Manufacturing Technology Management*, 23(3).

Paper IV

Hanson, R., Johansson, M.I. and Medbo, L. (2012), "In-plant materials supply by kitting – location of kit preparation". *Submitted to the International Journal of Production Research.*

A previous version of this paper was published in the proceedings of the XV International Scientific Conference on Industrial Systems, Novi Sad, Serbia, 2011.

Paper V

Hanson, R. and Finnsgård, C. (2012), "Impact of unit load size on in-plant materials supply efficiency". *Submitted to the International Journal of Production Economics.*

A previous version of this paper was published in the proceedings of the 21st International Conference on Production Research, Stuttgart, Germany, 2011.

Paper VI

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Robin Hanson

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1 Introduction

This thesis deals with in-plant materials supply, i.e. materials supply taking place within an assembly plant and supporting the assembly operations. Specifically, the thesis focuses on the materials feeding principles of "kitting" and "continuous supply".

Within the assembly industry, in-plant materials supply plays an important role in the competitiveness of a company. The in-plant materials supply should operate with a high efficiency and a high flexibility, as well as presenting the parts at the assembly stations in a manner that facilitates assembly. The materials feeding principles that are used constitute an integral part of the in-plant materials supply and can affect the performance of both the in-plant materials supply and the assembly. However, within industry, there is considerable confusion regarding which materials feeding principles should be used when. The existing research literature on the topic is far from exhaustive.

This introductory chapter first presents a background to the research area, describing the characteristics of the type of industry studied and the conditions that these characteristics set for the in-plant materials supply. Thereafter, the chapter introduces the materials feeding principles of kitting and continuous supply. A description is provided of the choice between kitting and continuous supply and the types of considerations that this choice entails. After that, based on gaps identified in the existing literature, the aim and scope of the thesis are presented before, finally, an outline of the thesis is given.

1.1 Background

In-plant materials supply is closely linked to the conditions under which the assembly plant is operating. Hence, in order to get an understanding of in-plant materials supply and of materials feeding principles, these conditions should be considered. The current section provides a background to the thesis and presents a description of the type of industry that is in focus.

Many industries today, such as the automotive industry, are characterised by end-customer demand for a wide variety of product models and variants. To respond to this demand for variety, production can be performed according to principles of "mass customisation". The concept of mass customisation can be said to denote production of medium-to-large volumes, with a flexibility that enables a large variety of products to be produced at a cost near that of mass produced items (Da Silveira et al., 2001). Generally, the concept of mass customisation also entails production in direct response to customer orders, i.e. some type of build-to-order production (Fredriksson and Gadde, 2005). An underlying principle is that even if the parts differ, the products assembled in a production facility have similar architectures and accordingly undergo the same basic assembly processes in more or less the same order (Fredriksson and Gadde, 2005). Often associated with mass customisation is the concept of mixed-model assembly, where different product models and variants are assembled in mixed sequence (Bock et al., 2006).

The large number of product variants, however, has implications for the material flows within the assembly plants. According to Berman (2002), mass customisation requires a logistics system that can support production in small lot sizes and with low inventory levels. Regardless of which product variant is being assembled, the necessary parts need to be available at the right assembly station at the time they are needed for assembly. Furthermore, in industry today, product life cycles are often short, product variety is great and products should be supplied to the customers in high quality, with short lead times and at low cost (Bukchin et al., 2002). Even though the in-plant materials supply does not supply the final customer directly, but instead supplies parts to the assembly operations, it must be able to contribute to the fulfilment of these demands.

With a build-to-order type of production, production volumes are closely linked to potential changes in customer demand; something which sets demands for flexibility of the production and of the in-plant materials supply. Hales and Andersen (2001) point out that materials supply is often focused on keeping low inventory levels, while at the same time trying to achieve a high availability of material. In contexts where demand is fluctuating, Hales and Andersen (2001) state that flexibility in the materials supply is a key to achieving this. Similarly, according to Lee (1997), the reconfigurability of a manufacturing system should be considered when it is designed, so that the system can be adapted to changes in demand.

The in-plant materials supply can also have a large impact on the assembly operations. In addition to the basic task of making the needed parts available at the point of assembly, the in-plant materials supply should be able to display the parts at the receiving assembly station in a manner that facilitates assembly. For example, the time the assembler needs to spend walking to fetch parts is dependent on the distance between where the parts are displayed and the assembly object (Klampfl et al., 2006; Wänström and Medbo, 2009; Finnsgård et al., 2011). Also, the product quality can be affected by how the parts are presented to the assemblers (Baudin, 2004). Because of the often large number of part variants in mixed-model assembly, it can also be difficult to find the space to display all part numbers at the assembly stations (Bukchin and Meller, 2005).

An in-plant materials supply system can be said to consist of a number of interrelated elements. For example, in the context of design of materials supply systems, Johansson (2006) divides a materials supply system into the six design areas of materials feeding, storage, transportation, materials handling, packaging, and manufacturing planning and control. The multitude of demands that exist on an in-plant materials supply system indicates an inherent complexity in these systems and a difficulty in designing them. Moreover, as pointed out by Hales and Andersen (2001), different contexts require different configurations of the in-plant materials supply. According to Hales and Andersen (2001, p. 10.15), "the industrial engineer should guard against simplistic, overly standardised, or one-size-fits-all decisions and plans". Accordingly, in order to design in-plant materials supply systems that can live up to all the different demands, an understanding is needed of the relations existing within in-plant materials supply systems, as well as of how the in-plant materials supply systems are related to their surroundings.

The materials feeding principles that are used constitute a central element of an in-plant materials supply system. The term "materials feeding principle" refers to how the parts are arranged as they are fed and presented to assembly, something that can impact both the materials supply operations and the receiving assembly operations. The materials feeding principles are tightly integrated with the rest of the in-plant materials supply system and a change in which materials feeding principles are used is likely to affect practically all other aspects of the in-plant materials supply. The materials feeding principles most commonly used within mass customised assembly today are kitting, continuous supply, batch supply, and sequencing (see Sections 1.2 and 2.1.1 for further descriptions of these principles). Sequencing can be used as a complement to another materials feeding principle, but is generally not used as the main materials feeding principle within an assembly plant. In contrast, each of the principles of kitting, continuous supply and batch supply can be used as the main materials feeding principle within an assembly plant, or in a section of an assembly plant. As already stated, the thesis focuses on kitting and continuous supply.

Within industry, the choice between using kitting or continuous supply is of central importance, but can be difficult to make. Both kitting and continuous supply are commonly occurring in industry, but knowledge is still limited regarding when each of these principles should best be applied. Among the performance areas that can be affected by the choice between kitting and continuous supply are product quality, inventory levels, flexibility and productivity (Bozer and McGinnis, 1992).

1.2 The materials feeding principles of kitting and continuous supply

With the principle of kitting, parts are delivered and presented to the assembly operations in pre-sorted kits, with each kit containing parts for one assembly object. Bozer and McGinnis (1992, p. 3) define a kit as "…a specific collection of components and/or subassemblies that together (i.e., in the same container) support one or more assembly operations for a given product or shop order". The use of kitting implies that parts from different part numbers are gathered into kits, before being delivered to the assembly stations. In mixed-model assembly, different assembly objects generally require different kit contents. Hence, each kit is then prepared so that its contents match a specific assembly object. Sometimes, especially within some companies, kitting is referred to as "SPS", which translates into "Set Part Supply", "Set Part Sequencing", "Set Part System" or "Set Part Strategy", depending on the source.

With the principle of continuous supply, a number of parts of each part number are stored at the assembly station where they are to be assembled. Hence, continuous supply is sometimes referred to as "line stocking". When continuous supply is used in a mixed-model assembly context, where different assembly objects require different parts, the assembler at each assembly station needs to pick the right parts to assemble on each assembly object. Often, continuous supply is associated with more direct materials flows within the assembly plant, compared to kitting, as parts can be delivered to the assembly stations without first being gathered into kits. A more thorough description of kitting and continuous supply is provided in Section 2.1.1.

Whether kitting or continuous supply is used in an industrial application can have significant impact on the performance of both assembly and in-plant materials supply. Each of the two materials feeding principles is associated with a number of benefits and drawbacks. Among the potential benefits of kitting are space-efficient parts presentation at the assembly stations (Bozer and McGinnis, 1992; Medbo, 2003; Caputo and Pelagagge, 2011), improved assembly quality (Sellers and Nof, 1986; Johansson, 1991; Bozer and McGinnis, 1992; Caputo and Pelagagge, 2011), shorter learning times (Johansson, 1991), a more holistic understanding of the assembly work (Medbo, 1999) and less time spent by the assembler searching for parts (Ding and Puvitharan, 1990; Johansson, 1991; Hua and Johnson, 2010; Caputo and Pelagagge, 2011; Limère et al., 2011). However, it is not obvious that kitting will always generate all of these benefits. For example, for kitting to improve assembly quality, the kits themselves need to be of a high quality. If there are quality deficiencies in the kits, this may lead to “cannibalisation”, meaning that faulty or missing parts are replaced by parts from other kits, which can cause problems such as extra handling (Bozer and McGinnis, 1992). There are also a number of potential benefits associated with continuous supply, compared to kitting. The kits need to be prepared before they are delivered to assembly, something that requires additional handling and space (Sellers and Nof, 1986; Bozer and McGinnis, 1992; Hua and Johnson, 2010). Additional transportation may also be necessary if kits are prepared in a separate area not linked to either storage or assembly. With continuous supply, instead, a relatively low number of handling operations can often be achieved in the materials supply, as the parts are often displayed in the supplier packages at the receiving assembly stations (Johansson, 1991).

1.3 The choice between kitting and continuous supply

The materials feeding principles constitute a central element of any in-plant materials supply system. Therefore, within industry, a choice of materials feeding principles must be made at some point before an in-plant materials supply system can be put to use. In addition, a choice of materials feeding principles can be made in an existing in-plant materials supply system, if there is question of changing from one principle to another. The current section provides a description of what a choice between kitting and continuous supply entails.

It should be noted that kitting can be combined with continuous supply, so that an assembly station is supplied with some parts by kitting and others by continuous supply (Baudin, 2002; Hua and Johnson, 2010; Caputo and Pelagagge, 2011; Limère et al., 2011). Hence, the choice between kitting and continuous supply can be said to include options of using a sole materials feeding principle, either kitting or continuous supply, or a combination of the two principles.

Before an appropriate choice between kitting and continuous supply can be made, the performance-related effects of choosing each of the two principles should be anticipated and considered. However, as found by Hua and Johnson (2010), who perform an extensive literature review in order to identify research issues on factors influencing the choice between kitting and continuous supply, the existing literature does not provide sufficient support to anticipate these performance-related effects. For example, within the area of materials handling efficiency, Hua and Johnson (2010) find that the current literature is insufficient for establishing how the total amount and cost of materials handling is affected by the choice between kitting and continuous supply. Similar knowledge gaps regarding the benefits and drawbacks of kitting and continuous supply are, by Hua and Johnson (2010), found in the performance areas of product quality, flexibility, inventory levels and overall space requirements within the plant.

As both kitting and continuous supply are associated with different benefits and drawbacks, it is not sufficient only to anticipate which performance-related effects can be expected from the use of each principle, but it is also necessary to set priorities between different performance areas. Which priorities should be made between different performance areas can be related to the context of the in-plant materials supply system. For example, plant layout and product variety, which are aspects that belong to the context of the in-plant materials supply system, can affect space availability and space requirements, and thereby the importance of space efficiency, both at the assembly stations and in other areas of the assembly plant, such as storage areas and kit preparation areas. Moreover, strategic aspects can influence how different performance areas are prioritised. If, for example, future growth in production volumes is planned, or if the product mix is planned to change, this needs to be considered in the choice between kitting and continuous supply.

The choice between kitting and continuous supply is not isolated from other aspects of the configuration of the in-plant materials supply system. Issues such as unit load size, transport frequency, location of different materials handling activities, materials handling equipment and work-load balancing should be considered when the choice is made. In relation to an existing in-plant materials supply system, a transition from one materials feeding principle to another can be associated with considerable changes to the whole in-plant materials supply system.

Overall, the complexity characterising the choice between kitting and continuous supply makes it difficult to formulate straightforward recommendations regarding which materials feeding principles should be used when. As stated above, and illustrated in Figure 1.1, both the configuration and the context of the in-plant materials supply system affect the performance associated with kitting and continuous supply and should therefore be considered when the choice is made. The term "configuration of the in-plant materials supply system" is in the thesis used to describe how the in-plant materials supply system is arranged, with regard to all elements of the system, including the materials feeding principles, the unit loads, the materials handling equipment, the delivery routes within the plant, etc. The term "context of the in-plant materials supply system" is used to denote everything that is not part of the in-plant materials supply system itself, but that could potentially influence its performance. In relation to the focus of the thesis, the production volumes and different product characteristics are examples of potentially relevant parts of the context of the in-plant materials supply system. Both the configuration and the context of an in-plant materials supply system will be further described in Chapter 2.

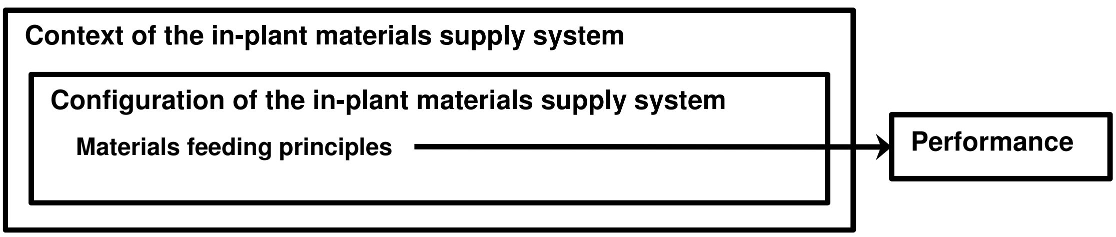


Figure 1.1 *Overview of the relation between materials feeding principles and performance, considering the configuration and the context of the in-plant materials supply system*

Different amounts of resources, such as man-hours, can be spent making a choice between kitting and continuous supply. A choice between kitting and continuous supply can be comprehensive, and be based on extensive investigations, analyses and discussions. The process of making a choice like this may involve a cross-functional project team, including people working within divisions of materials handling, assembly, and research and development. However, it is in practice common to apply guidelines that simplify the choice. Using guidelines, a choice between kitting and continuous supply can be made in an instant, by a single industrial engineer. Choices of this type can, for example, be made when a new part number is introduced and there is a need to decide how it should be supplied to the assembly stations. The guidelines that are used are simplified and consider only a limited number of aspects. As an example, found in a study from 2007 (Hanson and Johansson, 2007), continuous supply was then seen as the main materials feeding principle in the guidelines used in Swedish companies within the vehicle assembly industry. Materials feeding principles other than continuous supply would only be used if continuous supply, for some reason, was found not to be feasible to use. The motive for using continuous supply as the main materials feeding principle was, in the study of Hanson and Johansson (2007), found to be that continuous supply was considered to require the least effort in the materials supply operations.

Regardless of whether the choice between kitting and continuous supply is based on analyses and investigations or on simplified guidelines, there is a need for knowledge regarding the two principles and their applicability. Without extensive knowledge of each of the two principles, the cross-functional project group, described above, will not be able to make informed recommendations and the simplified guidelines are not likely to reflect all relevant aspects of the choice. Accordingly, knowledge of kitting and continuous supply and the applicability of each of the principles can be useful either directly in a process of choosing which principle to use, or indirectly, constituting a basis for guidelines that are used for supporting the choice. The fact that existing knowledge regarding kitting and continuous supply is limited implies that choices between kitting and continuous supply that are made within industry today do not properly consider all relevant aspects.

1.4 Research aim

This section summarises the main arguments of the background described above and, based on this summary, states the aim of the thesis.

It is clear that the choice between kitting and continuous supply can have considerable impact on both assembly and in-plant materials supply. It is also clear that the choice is often difficult and should be based on knowledge of which performance impact can be expected from the use of each principle, which, in turn, requires knowledge of the configuration of the entire materials supply system, including other aspects than only the materials feeding principles, as well as of the context of the in-plant materials supply system. However, considerable knowledge gaps exist regarding both kitting and continuous supply, and of how the two principles compare. Even though both kitting and continuous supply are established principles that have been in use for a long time, the existing literature does not provide sufficient support when it comes to the choice of which principle to use when.

In existing publications, little attention is paid to the interrelations between the materials feeding principles, the configuration of in-plant materials supply system as a whole, and the context of the in-plant materials supply system. (See Chapter 2 for a thorough literature review.) An exception is Hua and Johnson (2010), who acknowledge these interrelations and their importance, but do not address them other than by identifying issues for further research. Based on a literature review, Hua and Johnson (2010) conclude that "comparative research that investigates where each system [i.e. kitting and continuous supply] is most applicable, or that identifies the environments and factors that determine their applicability is lacking". Kitting has been stated to be preferable when production volumes are low and product variety is high, whereas continuous supply can instead be more suitable when production volumes are high and product variety is low (Sellers and Nof, 1986; Hua and Johnson, 2010; Caputo and Pelagagge, 2011). However, the current thesis focuses on mass customised assembly, where both production volumes and product variety are high, meaning that it is not obvious which of the two materials feeding principles is more suitable. Since the use of an inappropriate materials feeding principle can negatively affect the performance of both materials supply and assembly, further knowledge is thus needed. In order to support the choice between kitting and continuous supply within an in-plant materials supply system, the thesis addresses the existing knowledge gaps regarding how the performance associated with kitting and continuous supply relates to the configuration and to the context of the in-plant materials supply system. The thesis has the following aim:

The thesis aims to provide knowledge of how the configuration and the context of the in-plant materials supply system should be considered when a choice between kitting and continuous supply is made.

1.5 Scope

The thesis deals with the materials feeding principles of kitting and continuous supply within the in-plant materials supply in mass customised, manual assembly. In the thesis, the in-plant materials supply system is considered to include the equipment, the operations and the principles used in supplying parts to assembly. It is only the materials supply system within the plant that is studied, meaning that deliveries of parts from outside suppliers are not included in the system, but are instead seen as an input to it. Similarly, the assembly itself is not included in the materials supply system, but rather it is seen as the customer being served by it. The presentation of parts by the assembly stations is, however, included in the in-plant materials supply system and is seen as the interface with the customer, i.e. with assembly.

1.6 Thesis outline

Chapter 1 (Introduction) introduces the research area, provides a problem background, presents the aim of the thesis and gives an overview of the scope and the structure of the thesis.

Chapter 2 (Frame of reference) presents evidence from the existing literature that is relevant in relation to the focus of the thesis. Furthermore, based on shortcomings in the existing literature, the chapter derives and presents three research questions that are used to guide the studies of the thesis towards achieving the thesis aim.

Chapter 3 (Methodology) describes the methodology applied in the research.

Chapter 4 (Results) presents the results of the thesis, answering each of the three research questions.

Chapter 5 (Discussion and future research) discusses the results of the thesis and highlights areas that should be addressed in future research. The discussion includes both the generalisability of the results and their applicability, in relation both to research theory and to industrial practice.

Chapter 6 (Conclusions) presents the conclusions of the thesis.

2 Frame of reference

The current chapter constitutes the frame of reference of the thesis, presenting the existing literature that is relevant in relation to the focus of the thesis. In addition to reviewing the existing literature and presenting the theoretical foundations of the thesis, the chapter has the purpose of developing and presenting the research questions that are used to guide the research towards achieving the aim of the thesis.

Sections 2.1-2.3 are structured in accordance with Figure 1.1. Section 2.1 explains what in-plant materials supply is and of what elements an in-plant materials supply system can be said to consist. In Section 2.2, a presentation is given of how the context of an in-plant materials supply system can be described and of what factors can be relevant in relation to the choice between kitting and continuous supply. Thereafter, in Section 2.3, findings from the existing literature are presented, describing the impact that the choice between kitting and continuous supply can have on the performance of both in-plant materials supply and assembly. Section 2.4 presents four models that have been proposed for design processes of complex systems, such as production systems or materials supply systems, and discusses their applicability in relation to the choice between kitting and continuous supply. In Section 2.5 a review is presented of previously suggested decision support for the choice between kitting and continuous supply. Finally, based on gaps in the existing literature, Section 2.6 develops and presents the three research questions of the thesis.

2.1 General description of in-plant materials supply systems

Materials feeding principles, of which kitting and continuous supply are examples, constitute a central element of an in-plant materials supply system. However, to fully understand the role of the materials feeding principles within an assembly plant, it is necessary to be aware of the other elements of the in-plant materials supply system and of how the materials feeding principles relate to them.

As illustrated in Figure 2.1, this section focuses on the configuration of in-plant materials supply systems, which refers to how the in-plant materials supply system is arranged in terms of all of its constituent elements. Accordingly, this section describes what is meant by “in-plant materials supply” and of what elements an “in-plant materials supply system” can be said to consist.

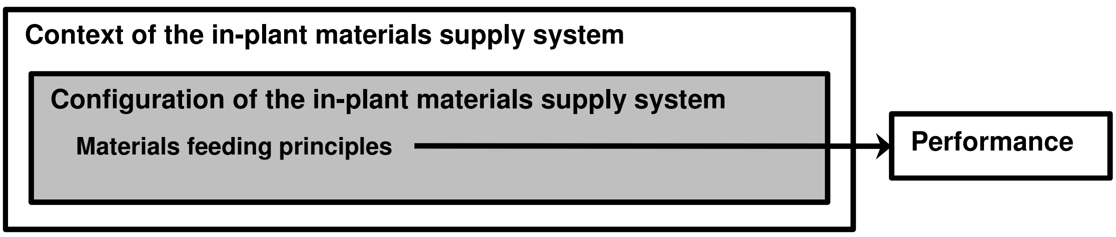


Figure 2.1 *The focus of the current section, highlighted in grey*

Depending on the use of the term, the purpose of “materials supply” can be said to be to supply parts from a supplier to production (Jonsson, 2008) or from a supplier, through a focal company, to industrial buyers (Johansson, 2006). In this thesis, the term “in-plant materials supply” is used to denote the supply of parts that takes place within an assembly plant, from goods reception, up to the point where the parts are delivered to and presented at the assembly stations. According to Hubka and Eder (1987, p. 128), "any system is always a constituent part of a super-system, and can itself be divided into sub-systems; systems constitute a hierarchy". Accordingly, an in-plant materials supply system can be seen as a sub-system of a materials supply system that stretches over a complete supply chain to a final customer. Similarly, it can be said that an in-plant materials supply system consists of further levels of sub-systems.

Numerous possibilities exist for how an in-plant materials supply system can be modelled and described. One comprehensive model is presented by Johansson (2006), who divides materials supply systems into six elements, where one of the elements is constituted by the materials feeding principles. Johansson (2006), who focuses on the design of materials supply systems, refers to these elements as "design areas". Because of the comprehensiveness of the model and its inclusion of the materials feeding principles as one distinct element, the model suggested by Johansson (2006) is useful in relation to the focus of the current thesis and it is hence used to structure the description of an in-plant materials supply system, presented in Sections 2.1.1-2.1.5. Even though Johansson (2006) mainly focuses on larger systems, stretching over several tiers of a supply chain, Johansson recognises that the model is applicable to in-plant materials supply too.

In the model suggested by Johansson (2006), a materials supply system consists of the six elements of materials feeding, storage, transportation, materials handling, packaging, and manufacturing planning and control. As acknowledged by Johansson (2006), transportation within facilities is generally included in the concept of materials handling. Accordingly, in line with the scope of the thesis, focusing on in-plant materials supply, transportation is here (in Section 2.1.2) discussed together with materials handling. The element of packaging, referring to physical packaging, rather than the activity of packaging, is in the current thesis expanded into "packaging and unit loads", as this is seen as a somewhat broader concept that includes packaging, but also units that are handled without packaging.

Based on the above, the current thesis considers in-plant materials supply systems to consist of the following elements:

- Materials feeding principles
- Materials handling
- Packaging and unit loads
- Manufacturing planning and control
- Inventory and storage

2.1.1 Materials feeding principles

As already stated, the concept of materials feeding principles refers to how the parts are arranged as they are fed and presented to assembly. The materials feeding principles of kitting and continuous supply, constituting the focus of the thesis, were briefly described already in Section 1.2. The current section provides a more thorough account of what each of these two materials feeding principles represents. Furthermore, the section puts kitting and continuous supply into perspective by clarifying that there exist further materials feeding principles too.

As the basis for the literature review of materials feeding principles presented in this section, a categorisation by Johansson (1991) is used. As shown in Figure 2.2, the first aspect considered relates to whether all part numbers or only a selection are displayed at one time, whereas the other aspect concerns whether the parts are sorted and presented according to their part number or according to the assembly object.

	Selection of part numbers	All part numbers
Sorted by part number	BATCH	CONTINUOUS
Sorted by assembly object	KITTING	

Figure 2.2 *Categorisation of materials feeding principles (Johansson, 1991)*

As can be seen in Figure 2.2, kitting implies that only a selection of part numbers is presented at a time and that these part numbers are sorted by assembly object. With continuous supply, instead, parts are sorted by part number and all part numbers are displayed at all times. The term "batch supply" refers to an approach where parts are supplied to the assembly for a number of assembly objects at a time (Johansson, 1991). The component racks by the assembly thus change contents from batch to batch, which can be accomplished either by removing half-full containers at the end of each batch or by keeping count of the inventory levels and making sure that only the number of parts needed are supplied for each batch.

If parts are "sorted by assembly object", as stated in the categorisation of Johansson (1991), this implies that they are delivered in accordance with the production sequence at the receiving assembly stations. This can be done either with kits or with single parts. Accordingly, in addition to the materials feeding principles of kitting, continuous supply and batch supply, which are included in the categorisation of Johansson (1991), sequential supply (of single parts) can be seen as a materials feeding principle of its own (Johansson, 2006). Like kitting, sequential supply implies that only a selection of part numbers is presented at a time, which means that very space-efficient parts presentation can be achieved at the assembly stations. Within industry, sequential supply is often used as a complement to continuous supply, so that most part numbers are supplied by continuous supply and sequential supply is applied to those parts that have a large number of variants.

The use of kitting entails parts of different part numbers being gathered and sorted into kits, in the operations that in this thesis are referred to as "kit preparation". In kit preparation, parts are picked from unit load specific containers into kits. Normally, the kits are held in containers (so-called kit containers), but they can also be held in racks or be completely without any load carrier. For example, if the kit preparation occurs directly at an assembly line, the parts of the kits can be placed in direct association with the assembly object, e.g. in or on the assembly object or on the assembly line. If the kit preparation does not occur in direct association with the assembly stations, the kits need to be transported there from the kit preparation area, in which case some type of load carrier is generally preferable. The configuration of the kits, e.g. in terms of which (if any) load carrier is used and in terms of how the parts are sorted and oriented within the kits, can have a significant impact both on how the kits are handled and on how well they present parts at the receiving assembly stations. For example, according to Medbo (2003), a well-structured kit can function as a work instruction for assembly.

Kits can be generic, so that all kits contain the same parts, but in mixed-model assembly, it is common for different kits to contain different parts, depending on which parts are required for each assembly object. This then means that the contents of the kits and the sequence with which they are delivered to the assembly stations should match the sequence of the assembly objects. Information regarding this sequence then needs to be available at the kit preparation area, so that the kits can be prepared in the correct sequence. Furthermore, kits can be classified as either being "stationary", supporting one assembly station each, or "travelling", moving with the assembly object along an assembly line, containing parts for several assembly stations (Bozer and McGinnis, 1992).

With continuous supply, materials flows can often be more direct than when kitting is used. As stated above, when continuous supply is used, each part number is presented separately at the receiving assembly station. This can often be achieved using the original packaging, in which the parts were sent from suppliers or internal supplying processes, meaning that no repacking is then required. Instead, part number specific unit loads are delivered to the receiving assembly station from storage or directly from a supplying process. However, if there are requirements for very space-efficient parts presentation, for example because of a large number of part variants, there may be need for repacking from larger into smaller unit loads when continuous supply is used (Johansson, 1991).

2.1.2 Materials handling

In some literature, the term "materials handling" is used in a broad sense, which overlaps or even coincides with the meaning of the term "in-plant materials supply" as it is used in this thesis. For example, Tompkins et al. (2003, p. 164) define materials handling as "providing the right amount of the right material, in the right condition, at the right place, in the right position, in the right sequence, and for the right cost, by the right method(s)". Similarly, Bozer (2001, p. 1504) states that materials handling involves "the configuration and size of the unit load(s), the determination of transfer lot size(s), the type of handling systems available (trip-based, conveyors or robots), the volume of flow, the frequency of flow, and the distances involved".

The current thesis, viewing materials handling as an element of the in-plant materials supply system, uses the term "materials handling" in a more narrow meaning, focusing only on physical handling and transportation of materials. In line with this use of the term, Öjmertz (1998a, p. 6) states that a conventional interpretation is that "materials handling includes movement within facilities, where lifting and putting down as well as packaging the materials are included". Materials handling includes all activities where materials are handled, such as transportation, lifting, picking, sorting, etc.

Traditionally, materials handling has often been seen as something wasteful, which should be minimised. Giust (1993), however, argues that by considering materials handling as strictly wasteful, there is a risk that no attention is paid to it, which then will result in poor performance. Similarly, Öjmertz (1998a) argues that materials handling can add value and that this is important to acknowledge. According to Öjmertz (1998b, p. 4), "the value-adding concept is used as a tool to discriminate between materials handling_activities which effect a desired change in a product and those which do not". Öjmertz (1998b, p. 5) also extends this further into the context of materials handling by stating that "an activity has a value-adding component if it contributes to the materials approaching the state desired in the final position of the studied supply chain". The difference between this desired final state and the actual situation is by Öjmertz (1998a) described through the concept of disorder, which in turn is explained through the four dimensions of mix, number, orientation and position. Accordingly, an activity is considered as value-adding if it, at least in one of the four dimensions, brings a change towards the desired final state. Öjmertz (1998a) further divides all materials handling into five types, which can affect the four dimensions of disorder. These five types of materials handling are picking, positioning, orienting, sorting and gathering. Table 2.1 shows the relation between the five types of materials handling and the four dimensions of disorder.

Table 2.1 *The relation between the types of materials handling and the dimensions of disorder (Öjmertz, 1998)*

		Handling types				
		Picking	**Positioning**	**Orienting**	**Sorting**	**Gathering**
Dimensions of disorder	**Number**	X			X	X
	Mix				X	X
	Orientation			X		
	Position	X	X			

Even though materials handling is necessary and, as argued by Öjmertz (1998a; 1998b), in many cases can be said to add value, the operations are nevertheless associated with time consumption and cost. Accordingly, *unnecessary* materials handling should be avoided as far as possible. In line with this, Wild (1995) states that for efficient materials handling to be achieved, the *need* for handling and movement activities should be eliminated, or reduced, as far as possible.

As noted by Bozer and McGinnis (1992), it is sometimes argued that kit preparation constitutes unnecessary materials handling and that continuous supply is therefore preferable to kitting. However, kit preparation can improve all four dimensions of disorder, as defined by Öjmertz (1998a) and illustrated in Table 2.1. Hence, the kit preparation is not necessarily wasteful. For example, the materials handling activities performed in the kit preparation can reduce materials handling in assembly. When comparing the amount of materials handling associated with kitting and continuous supply in order to make a choice between the two principles, materials handling activities in all processes affected by the choice should be considered, i.e. both materials supply and assembly.

Materials handling can be performed manually, but in many cases different types of handling equipment can be useful or even necessary. Baudin (2004) lists forklifts, pallet jacks, push carts, tugger trains, conveyors and Automated Guided Vehicles (AGVs) as being the most commonly used transportation equipment inside a plant. Of these, pallet jacks and push carts are generally hand driven and are mostly used for short transportation. In discussing forklifts, Baudin (2004) mentions their power and versatility, but also points out disadvantages such as cost and safety hazards. Furthermore, forklifts are not adapted for frequent deliveries to a great number of locations, which is often desirable in mass customised assembly. Instead, Baudin (2004) points out that the option of tugger trains has been developed especially for deliveries of this type. In another publication, Baudin (2002) further states that especially if delivery quantities are matched in such a way that the run-out time for different part numbers is approximately the same, tugger trains can be used to perform so-called milk run deliveries in regular, periodic intervals.

In addition to the equipment that can be used for actual transportation, there are also other types of equipment used for materials handling. In this context, Bagadia (1985) lists different types of cranes, hoists and lifts that can be used to facilitate handling. Benefits of equipment like this are, for example, that it enables the handling of heavy objects, lifting to or from otherwise inaccessible positions or that it improves ergonomics for the operators.

2.1.3 Packaging and unit loads

The concept of "packaging" here includes all kinds of load carriers, such as containers, pallets and racks. According to Chan et al. (2006), packaging can be divided into the two major types of industrial packaging and consumer packaging, where industrial packaging is concerned mainly with the preparation and protection of merchandise for shipment and storage and where consumer packaging is instead designed to enhance sales acceptance. In an assembly plant, packaging can be used for carrying parts of different assortments, for example for carrying collections of parts of a single part number or for carrying kits.

The concept of "unit loads" is sometimes discussed in relation to packaging. Tompkins et al. (2003, p. 174) discuss a definition according to which a unit load is "…a single item, a number of items or bulk material which is arranged and restrained so that the load can be stored, and picked up and moved between two locations as a single mass". This definition thus includes different types of packaging as well as singular units without packaging. Similarly, Bagadia (1985) lists six basic types of unit loads: pallet, sheet, rack, container, self-constrained unit load and palletless handling. Palletless handling is described by Bagadia (1985) as most commonly being made up of single items.

Goldsby and Martichenko (2005) identify a wide range of areas that are affected by the choice of packaging, including product protection, handling and storage efficiency, and handler safety and ergonomics. Similarly, Anthony (1985) states that there are four basic functions of packaging: containment, protection, communication and utility, where the latter refers to the interaction capacity between the packaging and its environment. In this interaction, Anthony (1985) includes activities such as opening and closing, but also handling through a facility. In order to achieve efficient materials handling, the interaction between the packaging and the materials handling is important (Anthony, 1985).

It is sometimes argued that size of packaging and unit loads should be as large as possible, as this minimises the number of times needed to handle the goods. For example, Hales and Andersen (2001) discuss the size of packaging and point out that a large packaging holding a large number of parts will reduce the number of transports necessary. At the same time, however, Hales and Andersen (2001) state that it is important to recognise that there are also drawbacks associated with using large packaging. The levels of work-in-process are likely to increase with large packaging and the space requirements are larger at the points of loading and use.

An important issue is how well the packaging presents the parts to assembly, as this can greatly affect the assembly operations. In the context of continuous supply, this is investigated by Wänström and Medbo (2009), who make a comparison between the Swedish and Japanese automotive industries. Wänström and Medbo (2009) observe that although standard packaging types are used in the Japanese plants, the number of different packaging types is much larger than in Sweden, and the packaging used reflects the characteristics of the parts it carries. The Japanese plants seem to have successfully focused on the point of use, i.e. the work of the assembler, in their packaging design for in-plant materials supply. Swedish companies instead seem to have concentrated more on designing cost-efficient systems up to the point of use, which has meant that large packages, often pallets, have been displayed in the component racks, which in turn has resulted in inefficient assembly operations (Wänström and Medbo, 2009).

In continuous supply contexts, there are case study reports showing that in addition to greatly reduced space requirements, a transition to smaller packaging can also improve the time efficiency (Wänström and Medbo, 2009), the ergonomic situation of the assembler (Finnsgård et al., 2011) and the flexibility for product volume and mix, as well as for product introductions and product modifications (Wänström and Medbo, 2009). The gains in time efficiency in these studies are the result of reduced walking distances, in turn resulting from significantly shortened component racks, and of reduced time for the actual picking of parts. According to Wänström and Medbo (2009), there are also cognitive effects of how the parts are presented and, with continuous supply, using small packages enhances the possibilities of presenting parts in a manner that reflects the assembly operations and that accordingly can facilitate learning.

With kitting, it is possible to let each kit container have a formal structure so that each part has a fixed position (Brynzér and Johansson, 1995). As a kit container includes several part numbers, it may be beneficial to fix each part in a certain position and orientation, as this can help create an overview for the assembler and can help in the arranging of the parts in accordance with the assembly operations. However, a kit container of this type has a limited flexibility (Brynzér and Johansson, 1995). It is also possible for a kit container to contain several kits. For example, a kit container can be a rack with multiple levels, in which several kits can be held (Limère et al. 2011).

In order to reduce the needed space at the assembly stations and to reduce the materials handling, Toyota has introduced the concept of “minomi”, where parts are transported and displayed at the assembly stations without containers. The parts are then handled individually, in stacks, or by use of simple carriers like cassettes or hooks. In order to minimise handling, the transfer from the materials supply unit (e.g. dolly) to the component rack is often performed by letting the parts slide over by the force of gravity (Liker and Meier, 2006). When effectively implemented, minomi can be used to eliminate forklifts from the materials supply, to reduce handling and to improve ergonomics (Liker and Meier, 2006). There are reports from Toyota’s Kentucky plant of drastically reduced space requirements at the assembly stations as the previously used part bins are exchanged for smaller part racks (Chappell, 2006a; Chappell, 2006b).

2.1.4 Manufacturing planning and control

Regardless of which materials feeding principle is used, there is a need for mechanisms that control the materials flows within the assembly plant, for example by initiating deliveries to the assembly stations and by ensuring that inventory levels are kept at a satisfactory level. "Manufacturing planning and control" refers to the activities concerned with planning and controlling all aspects of manufacturing, which includes the scheduling of machines and of materials (Vollmann et al., 2005). Many of the activities included in manufacturing planning and control thus fall outside the scope of the thesis, which is concerned only with in-plant materials supply and not with scheduling of machines or with materials supply from outside the plant. The activities that are relevant in relation to the scope of the thesis are those concerned with delivery initiation and control of the materials flows within the assembly plant.

To control the materials flows within an assembly plant, administration is needed and can often require considerable effort. Administrative activities include, for example, labelling, bar-code scanning, etc.

Delivery of parts within the assembly plant can be initiated based on how many parts have been consumed in the receiving assembly operations. This can be achieved by different types of "kanban" systems. The basic principles of a kanban system are that the consumption of one unit is signalled and then initiates replenishment (Vollmann et al., 2005). The use of actual consumption to trigger replenishment helps ensure that inventory is not accumulated at the assembly stations. Nicholas (1998) argues that in the right environment and with the right implementation, a kanban system can be used to achieve effective and simple systems with little inventory. Often, kanban systems are combined with milk-run deliveries, which are performed in certain predetermined time intervals, resulting in accumulation of orders and fewer deliveries (Nicholas, 1998).

Kanban systems were originally based on cards being used as signals, but, as stated by Baudin (2004), the use of physical kanban cards is associated with additional handling, since the kanbans must be collected, transported and registered. Similar functionality can be achieved by using, for example, empty containers or electronic systems for initiating replenishment instead of kanban cards (Baudin, 2004).

As opposed to being initiated based on actual, registered consumption, deliveries can also be initiated based on the planned production sequence combined with the bill-of-materials for each product (Choi and Lee, 2002; Golz et al., 2010; Emde and Boysen, 2012). With this approach, inventory levels at the assembly stations are kept track of and are automatically adjusted according to the consumption derived from the sequence of the assembly objects. When it is calculated that a predetermined reorder quantity has been reached, a new delivery will be initiated. As with the kanban type of system described above, it is possible to accumulate orders to achieve efficient deliveries, for example by use of milk-run deliveries. For this type of approach to function in mass customised assembly, it is imperative that correct information of the sequence of the assembly objects is available. Furthermore, the inventory levels must be kept track of so that part replenishment does not occur too early or too late. For in-plant materials supply by kitting to be reliable, accurate information must be available when the kits are prepared regarding the production sequence and regarding which parts should be included in each product (Schwind, 1992; Caputo and Pelagagge, 2011). Accordingly, the use of kitting in mixed-model assembly requires that systems are in place, keeping track of this information.

Depending on whether kitting or continuous supply is used, the number of feeding points (i.e. points to which parts are delivered) will differ. Continuous supply requires at least one feeding point per part number, whereas kitting requires only one feeding point per kit, and each kit contains several part numbers. The number of feeding points, in turn, will affect the deliveries to the assembly stations. It has been argued that the reduced number of feeding points facilitates visibility and control (Sellers and Nof, 1986; Bozer and McGinnis, 1992). On the other hand, in order to ensure that each kit contains the correct parts for the respective assembly object and that all kits are delivered in a sequence corresponding to the assembly objects at the assembly stations, there are high demands for correct information to be available in the bills-of-materials.

2.1.5 Storage and inventory

To function efficiently, each process step in a manufacturing process for physical products is dependent on a reliable availability of materials to process. Accordingly, in assembly, each part that is needed for a certain assembly operation must be available when that assembly operation is to take place. For the in-plant materials supply, this requires either that each process step is completely reliable or that materials buffers are in place and can function as decoupling points. Without such buffers, a disruption to one process, or to a materials flow between two processes, will result in a stoppage to the whole production process, both upstream and downstream. As stated by Smith (2001), buffers provide time-and-place utility by making sure that parts are available where they are needed, when they are needed. Furthermore, the use of buffers can be justified if placed between two processes that run on different schedules or produce in different product sequences (Giust, 1993). However, the carrying of inventory is often associated with considerable costs. Each storage point is associated with handling, which means that the number of storage points should not be larger than necessary (Hales and Andersen, 2001). In addition to the number of storage points, the inventory levels should not be higher than necessary. Carrying inventory is associated with costs of storage, insurance, breakage, deterioration, obsolescence and tied-up capital (Wild, 1995). Furthermore, according to just-in-time philosophy, the keeping of inventory hides problems and inefficiencies in the operations and can thus in some cases be said to result in production inefficiency costs (Slack et al., 2001).

Within a facility, storage can be said to be either centralised or decentralised. A centralised storage can offer the advantages of a high level of control over inventory, high space utilisation, and the possibility to use more highly automated equipment, whereas a decentralised storage instead can offer the advantage of having parts stored close to where they are needed (Hales and Andersen, 2001). There are different ways of organising decentralised storage and of allocating parts between different storage areas. For example, parts can be grouped according to their characteristics, such as size or storage requirements, or they can be grouped according to where they are to be used (Bennett and Forrester, 1993). By grouping parts together according to criteria like these, handling and control can often be facilitated, but at the same time, there is a risk of higher inventory levels compared to having a centralised storage, as the same part number may be stored in several locations (Bennett and Forrester, 1993). If storage is located close to the consuming operations, visual control over the inventory levels is facilitated, which can then eliminate the need for costly information systems (Hales and Andersen, 2001).

The choice between kitting and continuous supply can affect the configuration of the in-plant materials supply system profoundly and can, in doing so, redistribute inventory within the plant. The use of kitting, compared to continuous supply, can result in lower inventory levels at the assembly stations, associated with the parts presentation, but in higher inventory levels upstream of assembly, in association with the kit preparation (Hua and Johnson, 2010).

2.2 Context of the in-plant materials supply system

As previously stated, the performance associated with kitting and continuous supply has close links to the context of the in-plant materials supply system. This has been acknowledged in several publications (see Johansson, 1991; Bozer and McGinnis, 1992; Hua and Johnson, 2010; Caputo and Pelagagge, 2011), but there is still relatively little written about these links. As illustrated in Figure 2.3, the current section focuses on the context on the in-plant materials supply system, presenting findings from the literature regarding how the context, which is here divided into "contextual factors", can impact the performance associated with kitting and continuous supply. As stated in Section 1.3, the "context of the in-plant materials supply system" is in the thesis seen as everything that is not part of the in-plant materials supply system itself, but that could potentially influence its performance. This is a broad definition and the presentation below is not to be seen as a complete list of contextual factors, but rather as an account of the factors that have been identified in the existing literature focusing on kitting and continuous supply.

In the presentation below, the contextual factors have been divided into "product- and part-related factors", "production-related factors" and "layout-related factors".

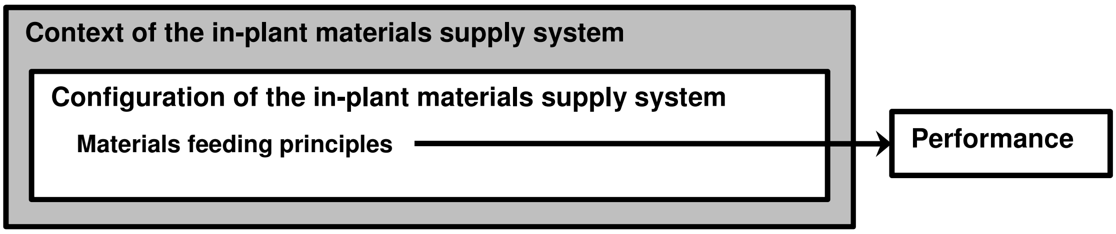


Figure 2.3 *The focus of the current section, highlighted in grey*

2.2.1 Product- and part-related factors

The physical characteristics of the products and parts being handled can have a decisive impact on how the in-plant materials supply system should be designed and on which materials feeding principle should be used.

The dimensions and the weight of the parts are aspects that are often stated to affect the choice between using kitting and continuous supply. Kitting is often applied in cases when the parts are relatively small and can be handled in small or medium-sized containers (Hua and Johnson, 2010). Limère et al. (2011) suggest that small parts can be more suitable for kitting than large parts, as it is easier to fit an additional small part into an existing kit, which will then reduce the man-hour consumption per part as the transport of kits will include a larger number of parts. Moreover, as stated by Caputo and Pelagagge (2011), some parts can be too large to fit into kit containers. On the other hand, there are reports of kitting being successfully applied to relatively large and heavy parts (Ding, 1992). It should be noted that kits do not necessarily need to be held in small containers, but that large containers and racks can also be used. For example, Medbo (1999) presents an example of a large kit rack holding parts for automobile assembly, including an entire exhaust pipe. However, large and heavy parts can be difficult to handle and can therefore require additional time during kit preparation, compared to smaller and lighter parts.

Another aspect that can affect the choice between kitting and continuous supply is the number of part and product variants. As stated in numerous publications (e.g. Bozer and McGinnis, 1992; Medbo, 2003; Caputo and Pelagagge, 2011), kitting enables more space-efficient parts presentation at the assembly stations than does continuous supply. Based on this, Limère et al. (2011) state that parts that have many variants are likely to free up much space at the assembly line when supplied by kitting instead of continuous supply. Similarly, Caputo and Pelagagge (2011) state that kitting is advantageous when the total number of components per assembly, including variants, is high, as for example in mass customisation. Johansson (1991) points out that when a large amount of part numbers need to be presented at an assembly station, it may be necessary to present the parts in packaging that is smaller than the original packaging sent from the supplier, in which case repacking to smaller packaging may be required (Johansson, 1991).

When discussing which parts should be supplied by kitting and which should be supplied by continuous supply, Caputo and Pelagagge (2011) suggest that the value of the parts should be used as a criterion. According to Caputo and Pelagagge (2011), kitting is associated with lower inventory levels, which means that for high-value parts, kitting has an advantage over continuous supply, and vice versa.

Bozer and McGinnis (1992) and Schwind (1992) point out that the use of kitting can be problematic when part quality is low and where parts therefore need to be replaced at the assembly stations. To solve a problem like this, it may be necessary to store spare components at some assembly stations (Bozer and McGinnis, 1992).

2.2.2 Production-related factors

Several publications state that the production volumes and product variety are key issues in relation to the choice between kitting and continuous supply. Kitting is often stated to be more suitable when production volumes are low and product variety is high, whereas continuous supply is stated to be more suitable when production volumes are instead high and product variety is low (Sellers and Nof, 1986; Hua and Johnson, 2010; Caputo and Pelagagge, 2011). Related to the production volumes is the assembly cycle time. In long cycle assembly, the display of parts would be very space consuming if materials were supplied according to the materials feeding principle of continuous supply (Medbo, 2003). Moreover, a kit can function as a work instruction, supporting the assembler (Medbo, 2003). This can be seen as more important for assembly with long work cycles, but can be relevant also to short-cycle assembly.

2.2.3 Layout-related factors

According to Benjaafar et al. (2002), layout decisions often fail to sufficiently accommodate the flexibility needed in a production plant and this can result in deteriorated performance in case of changes in production volumes or production mix. Related to this is the space available for presenting parts at the assembly stations. When parts are supplied by continuous supply, the availability of free space to present parts can increase the flexibility in terms of volume, mix and the potential for product modifications or introductions of new products (Wänström and Medbo, 2009). The size of the assembly stations can be partly related to the size of the products being assembled, but it can also be affected by the overall layout of the assembly plant and how the production processes are designed, e.g. whether assembly is performed along an assembly line or in some other manner. The space required for presenting parts may even decide the size of the assembly station, especially if the number of part variants is large and if large packaging is used to present parts (Finnsgård et al., 2011). If there is not enough space to present all part numbers at an assembly station, continuous supply is not a viable option, at least not for all part numbers (Caputo and Pelagagge, 2011).

The layout of the assembly plant further determines the transport distances within the plant. Together with the space availability in different areas of the assembly plant, the transport distances should be considered when a choice is made between kitting and continuous supply. For example, depending on where there is space available to place storage areas or kit preparation areas, transport distances associated with the use of kitting and continuous supply can differ. In presenting models for calculating performance associated with the use of kitting and continuous supply (see Section 2.4 for a thorough account of these models), Caputo and Pelagagge (2011) and Limère et al. (2011) consider the transport distances as one important aspect.

2.3 Potential performance impact associated with the choice between kitting and continuous supply

As has already been stated, the choice between kitting and continuous supply can affect several performance areas within both assembly and in-plant materials supply. Therefore, the effects of using kitting and continuous supply should be considered when the choice between the two materials feeding principles is made. As illustrated in Figure 2.4, the current section focuses on these effects and provides an account of what has previously been published regarding them. First, the section identifies which performance areas are likely to be affected by whether kitting or continuous supply is used, thereafter Sections 2.3.1-2.3.8 present more thorough information regarding the identified performance areas and regarding how they can be affected.

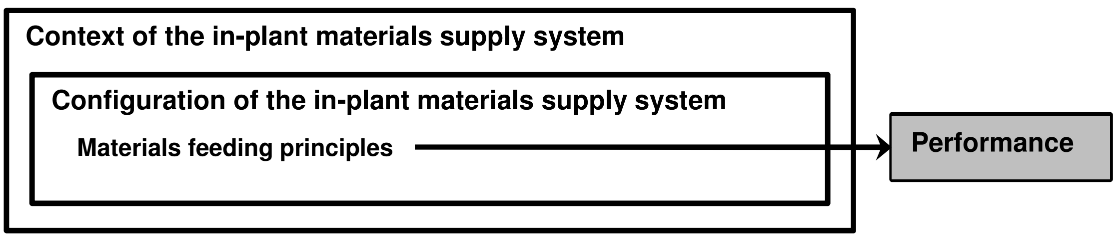


Figure 2.4 *The focus of the current section, highlighted in grey*

In the literature reviewed during the writing of the thesis, six publications were identified where relatively thorough comparisons are made between kitting and continuous supply: Sellers and Nof (1986), Johansson (1991), Bozer and McGinnis (1992), Hua and Johnson (2010), Caputo and Pelagagge (2011) and Limère et al. (2011). Table 2.2 presents an overview of the performance areas that are addressed in each of these publications.

Table 2.2 Performance areas brought up in the existing literature

	Man-hour consumption	Product quality	Flexibility	Inventory levels	Space consumption	Control and visibility	Product throughput time	Ergonomics	Investment cost
Sellers and Nof (1986)	X	X	X	X	X	X			
Johansson (1991)	X	X		X	X	X			
Bozer and McGinnis (1992)	X	X	X	X	X	X			
Hua and Johnson (2010)	X	X	X	X	X	X	X		
Caputo and Pelagagge (2011)	X	X	X	X	X	X			
Limère et al. (2011)	X		X		X			X	X

In order to be able to align and compare the performance areas included in the different publications presented in Table 2.2, a few adjustments have here been made to the terms used in the original publications. Accordingly, the term "man-hour consumption" in Table 2.2 is used to represent all statements from the reviewed publications indicating that the amount of work or the time to perform work (either in materials handling or in assembly) can be affected by the choice between kitting and continuous supply. Similarly, the term "flexibility" in Table 2.2 represents all statements that can be related to flexibility, such as product mix flexibility and ability to accommodate product changeovers.

All in all, there are a number of performance areas that are likely to be affected by the choice between kitting and continuous supply. Based on Table 2.2, it seems that man-hour consumption can be affected, as can product quality, flexibility, inventory levels, space requirement, control and visibility, product throughput time, ergonomics and investment cost. In line with the purpose of the current section, which is to provide an account of the effects of using kitting and continuous supply that have been brought forward in previous publications, all of these performance areas are therefore discussed more thoroughly in the following sub-sections (2.3.1-2.3.8). Inventory levels and space requirements are closely related and are therefore discussed in the same sub-section (2.3.3).

It should be noted that in addition to the performance areas accounted for in Table 2.2, several of the publications bring up the performance area of "cost" in relation to kitting and continuous supply. However, with the exception of investment cost, the impact on cost is in all papers linked to one or more of the other performance areas. For example, an increase in man-hour consumption or in inventory levels is associated with an increase in cost. Therefore, investment cost is the only type of cost that is discussed separately in the sections below.

2.3.1 Man-hour consumption

The use of kitting, compared to continuous supply, can affect the man-hour consumption in both assembly and materials supply. Man-hour consumption, in turn, is closely related to the running cost within production. As presented by Limère et al. (2011), the total materials handling time relevant when evaluating whether kitting or continuous supply should be used can be expressed as a sum of 1) materials handling time of the assembler, 2) materials handling time of the picker, 3) internal transport and 4) replenishment of the supermarket. In order for a comparison to be made, a corresponding sum of handling time can be calculated for a solution based on continuous supply.

At an assembly station, parts presentation by kitting will generally result in less man-hour consumption compared to continuous supply. This can be derived partly from the position where the parts are presented in relation to the position of the assembly object. In mixed-model assembly, where different product models need different part numbers, it may be difficult to find space at the assembly stations to present all part numbers in a manner that makes them easily accessible to the assemblers (Bukchin and Meller, 2005; Caputo and Pelagagge, 2011; Limère et al., 2011). If all part numbers are to be presented at the assembly stations, the walking distances required for the assemblers to fetch each part may be extended (Deechongkit and Srinon, 2009; Limère et al., 2011), which can then have a decisive impact on fetching times, as shown in previous research (Wänström and Medbo, 2009; Finnsgård et al., 2011). By presenting parts in small containers, relatively space-efficient parts presentation can be achieved with continuous supply (Wänström and Medbo, 2009; Neumann and Medbo, 2010), but kitting is nevertheless advantageous in most cases, because with kitting, not all part numbers need to be presented at once.

If assembly is performed along a continuously moving assembly line and continuous supply is used, the component racks are generally arranged so that the parts presentation should match the assembly cycle, ideally letting the assembly object pass by each part number exactly at the time when this part number is needed. However, in practice, it is next to impossible to present all parts in positions fully matching the position of the assembly object. Moreover, certain variability between work cycles always exists in the time required for each assembly task (Engström et al., 1996), something which for assembly along a continuously moving assembly line will cause variations in the distance between the assembly object and each part number that is needed from the component racks.

Another reason as to why man-hour consumption in assembly can be smaller when kitting is used, compared to continuous supply, is that the assembler does not need to spend time searching for parts (Ding and Puvitharan, 1990; Johansson, 1991; Bäckstrand, 2009; Hua and Johnson, 2010; Caputo and Pelagagge, 2011; Limère et al., 2011). As opposed to continuous supply, kitting implies that only the parts needed for each assembly object are presented to the assembler. Furthermore, a kit can be seen as a “loosely assembled product” and can facilitate assembly, especially when the parts are placed in correct positions in the kit container (Bozer and McGinnis, 1992).

Kitting can also be associated with increased man-hour consumption and cost of the assembly operations. In case incomplete or otherwise faulty kits are delivered to assembly, this can result in production delays and increased handling costs (Sellers and Nof, 1986).

The preparation of kits is associated with both time and cost (Sellers and Nof, 1986; Bozer and McGinnis, 1992). In line with this, reports exist of kitting being associated with larger man-hour consumption in the materials supply operations than continuous supply (Carlsson and Hensvold, 2008). However, in contrast to this, reports also exist of kitting reducing materials handling (Ding and Puvitharan, 1990; Henderson and

Kiran, 1993). In these reports, the kit containers seem to hold a larger number of parts than do the part number specific containers, resulting in a lower delivery frequency.

It should be noted that continuous supply too can be associated with a need for repacking parts before delivering them to the assembly stations. As stated in Section 2.2.1, this can be the case when the parts need to be presented at the assembly stations in a packaging that is smaller than the one sent from the supplier (Johansson, 1991).

2.3.2 Product quality and assembly support

Kitting has been stated to support high product quality, since the assembler does not need to be concerned with what parts to assemble, but can instead focus on how to assemble them (Bäckstrand, 2009). Medbo (2003) argues that, correctly structured, a kit can support assembly by functioning as a work instruction. If the parts are placed in the kit in a manner that reflects the assembly operations, kitting can facilitate learning and, consequently, reduce learning times and improve product quality (Johansson, 1991). However, for kitting to support high quality, this requires that the kits themselves have a high quality and that no parts are missing, incorrect or defective. Accordingly, quality must be assured in the preparation of kits, otherwise the potential quality gains associated with kitting will not be realised (Hua and Johnson, 2010). So called “pick-to-light” or “pick-to-voice” systems can be used to support high-quality picking, but these systems are often expensive to install (Brynzér and Johansson, 1995; Chen et al., 2003; Dallari et al., 2009).

When kitting is used, the kit preparation often means that each part is handled an additional time, compared to when continuous supply is used. In this additional handling, there is a risk of sensitive parts being scratched and damaged (Corakci, 2008).

2.3.3 Inventory levels and space requirements

Both kitting and continuous supply seem to hold both potential benefits and drawbacks in terms of inventory levels and space requirements. According to Hua and Johnson (2010), kitting is associated with less space requirements than continuous supply for presenting parts at the receiving assembly stations, but kitting may instead require more space upstream of assembly, for the kit preparation. Henderson and Kiran (1993) and Field (1997) report of continuous supply enabling reductions in inventory levels, as the kit preparation, according to these reports, is associated with additional build-up of inventory. Caputo and Pelagagge (2011) instead focus on inventory levels at the assembly stations and find that kitting is associated with lower inventory levels than continuous supply. Similarly, Sellers and Nof (1986) state that at the assembly stations, kitting can reduce inventory levels and associated floor space if the kits are not prepared in direct connection to assembly, as the part bins are then moved away.

In cases where there are part numbers that are used in multiple locations, continuous supply would result in multiple storage locations, which means that kitting could be advantageous (Johansson, 1991; Hua and Johnson, 2010). With continuous supply, the more part numbers that need to be presented, and the larger the unit loads, the more space is required at the assembly stations. The amount of part numbers that needs to be presented at each assembly station is related to the product and to the number of part variants that exist, but also to the assembly cycle time. The longer the cycle time, the more part numbers need to be assembled at each assembly station (Johansson, 1991).

2.3.4 Flexibility

Kitting is often considered to be associated with a higher flexibility than continuous supply (Sellers and Nof, 1986; Bozer and McGinnis, 1992). When continuous supply is used, the available space in the component racks constitutes a constraint to the amount of part numbers that can be presented at each assembly station. As described by Wänström and Medbo (2009), this is, in turn, associated with the level of flexibility in terms of being able to handle a large number of part variants or variations in production volume, as these types of flexibility can benefit from having free space available at the assembly stations. As further described by Wänström and Medbo (2009), with continuous supply, the use of small unit loads can enable presentation of a larger amount of part numbers.

Kitting, instead, offers more flexibility at each assembly station, as parts need only be presented for one assembly object at a time. Furthermore, product changeovers can be facilitated by the use of kitting, as parts and subassemblies are not staged at the assembly stations (Bozer and McGinnis, 1992). As described by Johansson (1991), and presented in the previous section on product quality and assembly support, kitting may also support the assembler by presenting parts in a manner that reflects the assembly operations, which in turn may further increase flexibility by facilitating changes in the assembly operations. In line with this, and as presented in Section 2.2.2, it is often stated that continuous supply is suitable for high-volume production of similar products, whereas kitting is better suited for production of customised products or a high variety of products (Sellers and Nof, 1986; Hua and Johnson, 2010; Caputo and Pelagagge, 2011).

In one respect, the flexibility associated with continuous supply is higher than that associated with kitting. The flexibility to change the sequence of the assembly objects can be reduced if there is a sequencing point upstream of the assembly stations, which is normally the case when kitting is used (Swaminathan and Nitsch, 2007).

2.3.5 Control and visibility

Related to the control and visibility of the materials flows within an assembly plant, there are both advantages and disadvantages associated with each of the materials feeding principles of kitting and continuous supply.

Kitting can, compared to continuous supply, offer a better control and visibility of the materials flows to the assembly stations, as only kit containers, instead of a wide array of part-number-specific containers, need to be delivered to the assembly stations (Bozer and McGinnis, 1992; Caputo and Pelagagge, 2011). On the other hand, if kit preparation is performed downstream of the main in-plant storage, the materials flows from storage to kit preparation area need the same level of control as the materials flows from storage to assembly line when continuous supply is used.

One benefit of kitting, compared to continuous supply, is that it can be easy to schedule the delivery of kits, assuming that the kits are delivered according to the sequence of the assembly objects (Limère et al., 2011). Each assembly object then consumes one kit, which makes it easy to anticipate when a new delivery to the assembly stations is necessary. Conversely, with continuous supply, it can be difficult to anticipate when each part number needs to be replenished at the assembly stations, as the consumption rate can vary depending on the mix of products being assembled.

In order for the kits to be prepared and delivered at the right time and in the right sequence, the use of kitting can increase requirements on information, compared to continuous supply (Caputo and Pelagagge, 2011). For example, if quality is to be ensured in the kit preparation, information needs to be available in the kit preparation area regarding which parts should be included in each kit. Schwind (1992) argues that the increased control that is required for kitting to be used can be seen as a benefit, as it sets demand for the bill of material to be updated. On the other hand, the smaller need for control that is associated with continuous supply is often seen as beneficial (Caputo and Pelagagge, 2011). Continuous supply can be arranged without any direct relation to the sequence of the assembly objects.

As pointed out by Johansson (1991), the reduction of materials-feeding points that can be associated with kitting, compared to continuous supply (see Section 2.3.3), can reduce work-in-process inventory and thereby increase control of materials in terms of deterioration and in terms of handling engineering changes. If parts are stored at each consuming assembly station and if consumption rate is low, part quality may deteriorate, which can then cause both scrap cost and quality deficiencies in the finished products. In relation to engineering changes or new product introductions, when it is necessary to replace old part numbers with new ones, a low number of feeding points is also beneficial.

As briefly mentioned in Chapter 1, in case quality deficiencies are found in a kit, this may lead to “cannibalisation”, meaning that faulty or missing parts from one kit are replaced by parts from other kits, resulting in missing parts in these kits, which can cause complicated shortages and double handling (Bozer and McGinnis, 1992).

2.3.6 Product throughput time

Very little has been published regarding how product throughput time can be affected by whether kitting or continuous supply is used. Of the publications reviewed during the writing of the thesis, only Hua and Johnson (2010) even mention this performance area in relation to kitting and continuous supply. Moreover, Hua and Johnson (2010) do not bring up throughput time in relation to mixed-model assembly, but only in relation to batch production, and do not present any conclusive information as to which materials feeding principle is associated with the shorter throughput time.

Based on the existing literature, it is clear that kitting holds a potential to reduce the non-value-added time spent by the assemblers, by presenting parts closer to the assembly object and by reducing the time for searching for parts (Ding and Puvitharan, 1990; Johansson, 1991; Bäckstrand, 2009; Hua and Johnson, 2010; Caputo and Pelagagge, 2011; Limère et al., 2011). In manual assembly, the non-value-added time spent by the assemblers is associated with the assembly object having to wait. Accordingly, by enabling the assemblers to spend a greater proportion of their time assembling, instead of fetching parts, it seems that kitting can enable a reduction in product throughput time, compared to continuous supply. In effect, the use of kitting, instead of continuous supply, results in tasks being performed in parallel instead of in sequence: instead of the assembler spending time fetching parts before assembling them, the main part of the time for fetching parts is spent by someone else, in a kit preparation area.

By reducing the product throughput time at an assembly station, or at an assembly line, it is possible to produce a larger number of units in a given period of time, meaning that the production capacity for that assembly station, or assembly line, can be increased. However, in order to achieve this, the amount of resources, such as man-hours, spent in the kit preparation needs to increase.

2.3.7 Ergonomics

Ergonomics is an area that is highly relevant in relation to materials handling. However, like the performance area of product throughput time, very little has been published regarding how ergonomics can be affected by whether kitting or continuous supply is used. Limère et al. (2011) state that kitting can offer better ergonomics than continuous supply. They base this statement on a reference to Finnsgård et al. (2011), stating that ergonomics at the assembly station can be improved by parts presentation in small containers, compared to large pallets. It is possible that the space-efficient parts presentation associated with kitting (Bozer and McGinnis, 1992; Medbo, 2003; Caputo and Pelagagge, 2011) can facilitate ergonomically suitable parts presentation at the assembly stations. On the other hand, in the materials supply, the use of kitting is associated with additional handling for preparing the kits (Sellers and Nof, 1986; Bozer and McGinnis, 1992), which could be associated with a risk of ergonomics problems. Generally, the risk of ergonomics problems is greater for parts that are heavy and unwieldy (Matt et al., 2011).

2.3.8 Investment cost

Limère et al. (2011) bring up the issue of the investment cost associated with setting up an in-plant materials supply system based on kitting or continuous supply. However, Limère et al. (2011) assume that neither system requires any automation and, based on this, conclude that the investment cost in both systems is negligible compared to the labour cost. Deechongkit and Srinon (2009) have a different perspective than Limère et al. (2011) and argue that in a mass-customisation context, where there is a large amount of different part variants, the use of kitting can, because of the space-efficient parts presentation, enable a shorter assembly line, and can thus reduce investment cost considerably, compared to continuous supply.

As stated in Section 2.3.2, in relation to product quality and assembly support, "pick-to-light" or "pick-to-voice" systems that can be used to support picking quality in kit preparation are often expensive to install.

2.4 Models for the design of production and materials supply systems

When making a choice between kitting and continuous supply, numerous aspects need to be considered, including both the configuration and the context of the in-plant materials supply system. It seems that a structured approach can be beneficial in order to consider all these aspects and, thereby, in order to make an appropriate choice.

Within the existing literature, no publications have been found focusing on describing processes for making a choice between kitting and continuous supply. Instead, this section presents examples of models of design processes that have been suggested in relation to the related areas of design of systems for materials supply, production and assembly. In Section 2.4.1, four design processes, suggested by Bennett and Forrester (1993), Wu (1994), Bellgran (1998) and Johansson (2006), are presented. This is by no means an exhaustive account of the existing literature on design processes, but serves to exemplify how design processes suggested in the previous literature are structured and function as a basis for a discussion presented in Section 2.4.2, regarding how a structured process may be of help in relation to a choice between kitting and continuous supply. The models presented in Section 2.4.1 have been selected because they constitute relatively comprehensive approaches towards designing complex systems, and because they display differences in terms of the type of system they focus on; design processes for materials supply, production and assembly systems are all potentially different, but at the same time they are relevant to consider in relation to a design process for in-plant materials supply systems.

2.4.1 Descriptions of previously suggested design models

Johansson (2006) presents a model of a design process for materials supply systems stretching over several tiers of a supply chain. The model includes, but does not focus on, in-plant materials supply and the choice of materials feeding principles. The model is illustrated in Figure 2.5 and consists of the four phases of planning, concept development, system-level design and detail design. The choice of materials feeding principles is included in the phase of "system-level design" and is referred to as "materials feeding" in Figure 2.5. In the phase of "detail design", the materials supply system is configured in detail, including aspects such as the choice of transportation and handling equipment and packaging design.

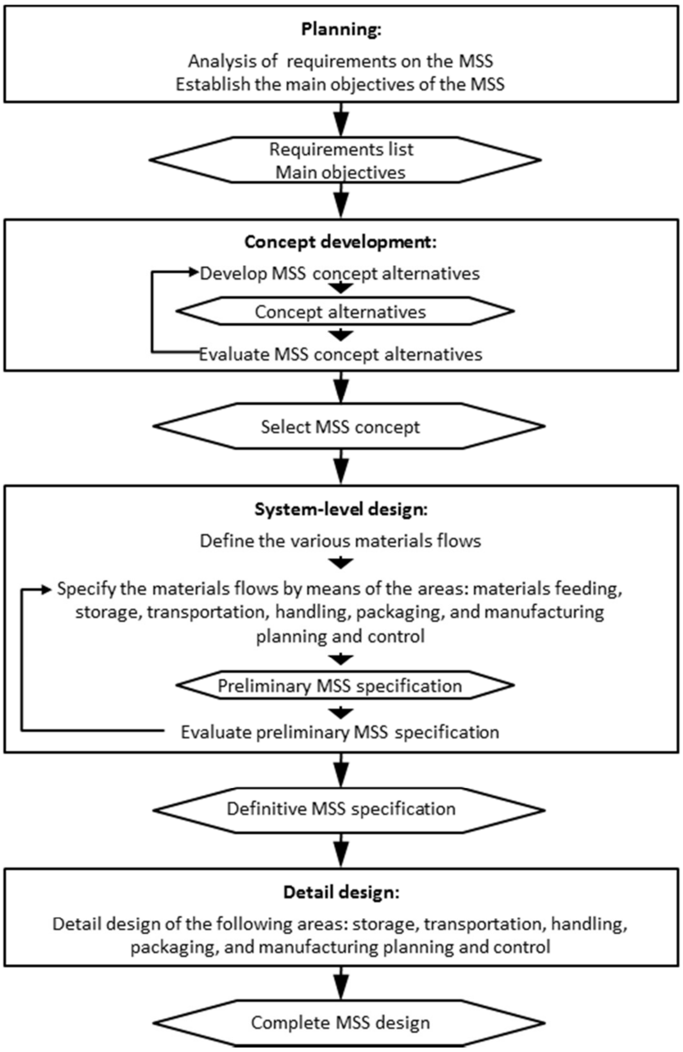


Figure 2.5 *The materials supply system (MSS) design process, according to Johansson (2006)*

As stated by Johansson (2006), the boundaries between the different phases are not always distinct and may differ between companies. The general idea, however, is that the configuration of the materials supply system gets more clearly defined for each phase and that after the last phase, the detailed design, the configuration of the materials supply system is completely decided.

Johansson (2006) proposes the model in the context of product development projects, implying that the design process takes place before the materials supply system is put to use. As discussed before, however, the choice between kitting and continuous supply can also be made in relation to an existing in-plant materials supply system, where there is a question of whether or not to change from one materials feeding principle to another.

In discussing design of production systems, Bennett and Forrester (1993) use the three design areas of layout, storage and transportation. Each of the design areas is by Bennett and Forrester (1993) described by the use of three levels that differ in their level of detail: factory level, module level and utility level. Similar to the design phases suggested by Johansson (2006), Bennett and Forrester (1993) suggest that the system should be designed level by level, so that the factory level is designed first, thereafter the module level and finally the utility level. The factory level here includes factory-wide decisions regarding production configuration, degree of centralisation and scope for automation. The module level consists of decisions regarding more specific configuration, e.g. regarding the transport or the level of automation used within a production module. Finally, the utility level concerns decisions made on an even more detailed level, focusing on specific choices of hardware within the production system. Before finishing each design level, Bennett and Forrester (1993) suggest that the proposed design should be evaluated and compared to performance-related objectives that have been set up before the design process. If the evaluation is not satisfactory, the proposed design should be revised.

Another process for designing production systems is suggested by Wu (1994). Wu (1994) suggests that the existing production system should first be analysed and after that, objectives should be set for the design process. This way, Wu (1994) argues that the objectives will reflect the existing system, so that a realistic starting point is achieved, but the creativity in the design will not be restricted. After the objectives have been set, the design process suggested by Wu (1994) includes the two major phases of “conceptual modelling” and “detailed design”. The conceptual modelling develops the basic principles for how the system should function and includes make-or-buy decisions and decisions regarding long-term production capacity. During the detailed design phase, decisions are made regarding the detailed layout of the assembly plant, manufacturing equipment and in-plant transportation and storage. In describing the detailed design, Wu (1994) does not discuss in detail how the in-plant materials supply should be configured, e.g. in terms of materials feeding principles. Wu (1994) suggests that towards the end of both the conceptual modelling and the detailed design, the proposed design should be evaluated in relation to the initial objectives and that, based on the evaluation, the design should either be accepted, further developed or discarded.

Bellgran (1998) presents a method to support the design of assembly systems. The method consists of eight phases, each of which contains several design steps. The different phases are partly conducted in parallel and partly in sequence. One step within the phase “creation of conceptual assembly system alternatives”, which is the sixth phase of the method suggested by Bellgran (1998), focuses on the materials flow to the assembly stations. In this step, issues regarding packaging, storage and type of materials handling equipment are dealt with, but Bellgran (1998) does not address the materials feeding principles. After the creation of conceptual assembly system alternatives, Bellgran (1998) suggests that an evaluation is performed, determining whether the proposed design is satisfactory or needs to be improved. After the evaluation, Bellgran (1998) suggests that the design is specified further, during a “detailed design” phase.

2.4.2 Discussion of previously suggested design processes

A choice between kitting and continuous supply is similar to a design process, because of the many elements of the in-plant materials supply system that need to be adapted based on the choice of materials feeding principle. For example, in an existing assembly plant, a change from continuous supply to kitting requires that kit preparation is introduced. Per definition, this is associated with changes to the materials handling. Most likely, changes will also need to be made to the storage of parts, for example in relation to the kit preparation area, to the unit loads used and to the planning and control. Similarly, in the design of a new in-plant materials supply system, the other elements of the in-plant materials supply system must be designed in conjunction with the choice of the materials feeding principle.

The use of a structured process for designing a complex system, such as a production system or a materials supply system, makes it easier to consider all relevant aspects, thereby contributing to making the design process both more effective and more efficient. Hence, a process similar to those described in Section 2.4.1 should be useful in relation to the choice between kitting and continuous supply, where a large number of aspects need to be considered. This applies both to a choice made in relation to an existing in-plant materials supply system and to a system that has not yet been put to use.

The design processes presented in the previous section display a number of similarities in terms of their basic composition. Each of the design processes is iterative in nature, consisting of a number of separate phases, during which the configuration of the system, be it a materials supply system or a production or assembly system, gets gradually more clearly defined. Moreover, before a preliminary, conceptual configuration of the system is passed on to the next design phase, it is evaluated and its expected performance is compared to a set of objectives that have been defined beforehand. If the performance is not satisfactory, adjustments are made.

All of the reviewed models have a scope that is much broader than that of in-plant materials supply and, accordingly, none of the models provides much support to the choice between kitting and continuous supply. The choice of materials feeding principles is explicitly included only in the model proposed by Johansson (2006) and there it receives only limited attention. A noteworthy feature of the model proposed by Johansson (2006) is that the choice of materials feeding principle is made before the rest of the materials supply system is specified in detail. This reflects the central role of the materials feeding principles within a materials supply system.

2.5 Previously suggested decision support for the choice between kitting and continuous supply

In previous publications, models have been suggested that can be used to compare the relative performance of kitting and continuous supply. Bozer and McGinnis (1992), Caputo and Pelagagge (2011) and Limère et al. (2011) all suggest models with this purpose. A similar type of model, though not considering the option of continuous supply, is suggested by Battini et al. (2009). All these models provide means of calculating performance, in varying performance areas, based on input from the operations being considered, in terms of, for example, container sizes, production volumes and man-hour consumption for different activities. This section presents a review of each of these publications. In Section 2.5.1, each of the models is described. Thereafter, in Section 2.5.2, a critical discussion of the models is presented. The critical discussion identifies both benefits and limitations of the models. In identifying the limitations, the discussion constitutes part of the justification of the research presented in the thesis.

2.5.1 Descriptions of previously suggested decision support

Bozer and McGinnis (1992) provide both a general description of kitting and continuous supply, including an account of benefits and drawbacks of the two principles, and a model for calculating performance with each principle. Bozer and

McGinnis (1992) state that their model is only meant to be used as a preliminary decision support and that it could serve as a “starting point” or “benchmark” for future models. They further state that because of knowledge gaps, it would be “not only far from straightforward but premature” to develop a comprehensive model that would capture all the interrelations that exist between the materials feeding principles and their surroundings, especially since the interrelations seem to vary between different cases (Bozer and McGinnis, 1992, p. 7).

The model proposed by Bozer and McGinnis (1992) consists of equations that, for each of the principles of kitting and continuous supply, can be used to calculate container handling, space requirements and levels of work-in-process inventory. The model considers only effects in the materials supply and, accordingly, ignores any effects that the choice between kitting and continuous supply can have on assembly. In the materials supply, only the container handling is considered, whereas the materials handling associated with picking parts into kits is ignored. Both stationary and travelling kits can be considered in the model.

The input needed to apply the suggested equations to an industrial case is relatively straightforward to attain. In order to calculate the amount of materials handling, which by Bozer and McGinnis (1992) is measured as the number of containers handled each day, input is needed regarding the number of end products produced each day, the number of parts included in each product and the number of parts in each container. The equations for calculating the floor space required for storing containers at the assembly stations requires input regarding the number of containers stored at each assembly station and regarding the floor space required for storing each container. Similarly, the equations for calculating the work-in-process inventory require input regarding the number of containers stored at each assembly station and regarding how many parts are included in each of these containers.

Battini et al. (2009) present a model that compares three different approaches for supplying parts to assembly, which are referred to as “pallet to work station”, “trolley to work station” and “kit to assembly line”. According to the terminology of the thesis, the “pallet to work station” approach is equivalent to batch supply, where different part numbers are displayed at each assembly station depending on which product is being assembled, and where half-full pallets are brought back to the storage when they are no longer needed at the assembly station. The “trolley to work station”, and “kit to assembly line” approaches are equivalent to kitting by stationary kits and kitting by travelling kits, respectively. Hence, the model suggested by Battini et al. (2009) does not consider the option of supplying parts by continuous supply. The model bases its comparison of the three different approaches on man-hour consumption in materials handling, including materials handling of the assembler, materials handling of the picker in the kit preparation and the transportation parts from the kit preparation area to the assembly station.

To calculate overall man-hour consumption, the model of Battini et al. (2009) requires input regarding the average man-hours spent on the activities of picking parts during the kit preparation and transporting them to assembly, as well as regarding all man-hours spent by the assembler handling materials. In the model, the inputs regarding man-hours for transport can be broken down into transport distances and average transport velocity.

Similar to Bozer and McGinnis (1992), Caputo and Pelagagge (2011) propose a model for evaluating and comparing performance related to both kitting and continuous supply. Furthermore, based on the literature, Caputo and Pelagagge (2011) present an overview of kitting and continuous supply. This overview includes a presentation of benefits and drawbacks associated with both principles, in terms of the performance areas of man-hour consumption, product quality, flexibility, inventory levels, space consumption, and control and visibility (see Table 2.2).

Instead of comparing kitting only to continuous supply, Caputo and Pelagagge (2011) distinguish between two different options for continuous supply, which they refer to as “kanban” and “line stocking”, and compare kitting to both of these options. The basic difference between the kanban option and the line-stocking option is the size of the unit loads used for delivering and presenting parts at the assembly stations, where the kanban option is associated with small unit loads that are replenished frequently and where the line-stocking option is associated with large unit loads that require more space at the assembly line and that are replenished with a lower frequency. Moreover, as implied by the term, the “kanban” option is associated with delivery initiation based on kanban signals, whereas the option of line stocking is associated with periodic deliveries that seem to be performed at regular intervals, without any actual delivery initiation signal.

The model proposed by Caputo and Pelagagge (2011) is based on a number of assumptions. The model assumes that the kits are prepared one at a time, in a single storage location within the assembly plant, by personnel from the materials handling division of the company, as opposed to the assembly division, and that the kits are delivered to and used at a single-product assembly line. Only travelling kits are considered, as opposed to stationary kits.

The model of Caputo and Pelagagge (2011) is, to some extent, based on the model of Bozer and McGinnis (1992). Similar to the model of Bozer and McGinnis (1992), the model of Caputo and Pelagagge (2011) consists of equations that can be used to calculate performance associated with both kitting and continuous supply. However, as opposed to the model of Bozer and McGinnis (1992), the model of Caputo and Pelagagge (2011) focuses on the man-hour consumption in materials handling, including the kit preparation. The model further includes performance in terms of space consumption and inventory levels at the assembly stations. The model requires input regarding the man-hours required for different activities, such as locating and reaching a part in the storage area, picking a part (in the kit preparation), and performing a transport between the storage location and the assembly line. Input is also required regarding the volume of each part and of each container, and of the number of containers brought in each transport.

In addition to enabling the calculation of man-hour consumption in materials handling, the model proposed by Caputo and Pelagagge (2011) can be used for evaluating combinations of kitting and continuous supply. These combinations of kitting and continuous supply are compared based on a classification of parts, where the most suitable materials feeding principle, out of kitting, kanban and line stocking, is meant to be determined for each class. Caputo and Pelagagge (2011) use a Pareto ABC classification, based on the economic value of the parts. An underlying assumption behind this type of classification is that inventory levels will be much lower when kitting is used, meaning that the use of economic value as a basis for classification can enable a low overall holding cost.

Caputo and Pelagagge (2011) further acknowledge that in relation to combinations of kitting and continuous supply, other criteria than the economic value of the parts may be used as the basis for a classification of parts. As an example, they mention that the degree of component commonality, i.e. the degree to which different parts are common to all end products, could be relevant to use. With a classification based on this criterion, Caputo and Pelagagge (2011) suggest that the parts with the lowest degree of commonality are likely to be the ones most suitable for kitting.

Limère et al. (2011) too propose a model to be used for choosing between kitting and continuous supply. Moreover, Limère et al. (2011) first provide a general description of each of the two materials feeding principles of kitting and continuous supply. Included in this general description, a number of benefits and drawbacks of kitting, in relation to continuous supply, are presented.

In the model of Limère et al. (2011), only stationary kits are considered, as opposed to travelling kits. In their model, Limère et al. (2011) assume that the kits are prepared in a central kit preparation area, which in turn is replenished from two separate warehouses, one for smaller containers and one for pallets. Limère et al. (2011) further assume that the pickers walk to fetch parts within the kit preparation area and that the kits are prepared in batches.

The model focuses on man-hour consumption and the associated cost thereof. It consists of equations that can be used for calculating man-hour consumption both in in-plant materials supply, including the kit preparation, and in assembly. The model is reliant on detailed input for each part number. For the picking of parts, the model requires input regarding the man-hours required for searching for a part and the walking distances and the walking velocity for fetching the part. For continuous supply, this input refers to the activities at the assembly line, whereas for kitting, it refers to the activities both at the assembly line and in the kit preparation area, as each part needs to be picked twice when kitting is used. Similarly, for the transport of parts, both to the kit preparation area and to the assembly line, the model requires, for each part number, input regarding the transport distances, the number of parts per unit load and the number of unit loads transported on each trip. Input is also needed regarding the velocity of the materials handling equipment.

The model proposed by Limère et al. (2011) focuses on minimising man-hours and associated cost, but also includes considerations regarding the space available at the assembly stations. Accordingly, the model includes equations for calculating the accumulated length of all unit loads, for each assembly station, along the assembly line and for comparing this accumulated length with the available length along the assembly stations. The model allows for vertical stacking of smaller containers, but not for pallets.

2.5.2 Critical discussion of previously suggested decision support

Table 2.3 summarises the characteristics of the models proposed by Bozer and McGinnis (1992), Battini et al. (2009), Caputo and Pelagagge (2011) and Limère et al. (2011). All of the models have the benefit of generating quantitative results, making it easy to compare the performance associated with each materials feeding principle. Moreover, the basic composition of each of the models is easy to understand, each model calculating a sum of total resource consumption within a specified performance area, such as space consumption or man-hour consumption.

The models differ from each other in terms of the level of detail, which affects both the input they require and the results they generate. The models of Battini et al. (2009), Caputo and Pelagagge (2011) and Limère et al. (2011) all rely on detailed input data that, in many cases, can be difficult to attain, for example regarding the man-hour consumption required for performing different activities in materials supply and assembly. One of the main problems associated with the choice between kitting and continuous supply is that the performance associated with each principle is difficult to foresee. Hence, a comparison of the type suggested in the models of Battini et al. (2009), Caputo and Pelagagge (2011) and Limère et al. (2011) is in practice often difficult to make. The model suggested by Bozer and McGinnis (1992) relies on data that are easier to attain, but on the other hand, it generates comparisons with a relatively low level of detail.

None of the models pays much attention to the relations that exist between performance related to the materials feeding principles and any contextual factors, related to for example the products, or the production facility. Exceptions are the transport distances, which are included in the calculations of man-hour consumption for transportation (Battini et al., 2009, Caputo and Pelagagge, 2011, Limère et al., 2011), and the number of parts included in each container (Bozer and McGinnis, 1992; Caputo and Pelagagge, 2011, Limère et al., 2011), which is related to the part characteristics in terms of size and weight.

Bozer and McGinnis (1992), Caputo and Pelagagge (2011) and Limère et al. (2011) all bring up a large number of performance areas as potentially relevant to consider, but include only a selection of them in their respective models. Accordingly, neither of the models considers the full scope of performance areas identified in Section 2.3 and displayed in Table 2.2. As presented in Section 2.5.1, the model of Bozer and McGinnis (1992) considers container handling, space requirements and levels of work-in-process inventory; Battini et al. (2009) consider only man-hour consumption; Caputo and Pelagagge (2011) consider man-hour consumption and space requirements; Limère et al. (2011) focus on man-hour consumption, but also consider the space availability at the assembly line. Battini et al. (2009), Caputo and Pelagagge (2011) and Limère et al. (2011) further relate the man-hour consumption to monetary cost. Moreover, out of these models, only the models of Battini et al. (2009) and Limère et al. (2011) include the man-hour consumption of the assembly operators, whereas the models of Bozer and McGinnis (1992) and Caputo and Pelagagge (2011) include only the in-plant materials supply operations.

As presented in Section 2.5.1, all of the models are based on a number of assumptions that limit their applicability. The model of Bozer and McGinnis (1992) considers only a single container type for continuous supply and another for kitting. The model of Caputo and Pelagagge (2011) considers only travelling kits. Conversely, the model of Limère et al. (2011) considers only stationary kits.

Table 2.3 Overview of the characteristics of the reviewed models

	Materials feeding principles considered	Performance areas considered	Operations considered	Type of kits considered	Required level of detail of input data	Level of detail of output data
Bozer and McGinnis (1992)	Kitting and continuous supply	No. of containers handled, space requirements and inventory levels	Transportation to assembly	Travelling and stationary kits	Low	Low
Battini et al. (2009)	Kitting and batch supply	Man-hour consumption	Kit preparation, transportation to assembly, and assembly	Travelling and stationary kits	High	High
Caputo and Pelagagge (2011)	Kitting and continuous supply	Man-hour consumption, space requirements and inventory levels	Kit preparation and transportation to assembly	Travelling kits	High	High
Limère et al. (2011)	Kitting and continuous supply	Man-hour consumption	Kit preparation, transportation to kit preparation and to assembly, and assembly	Stationary kits	High	High

2.6 Research questions

Based on the literature presented in Sections 2.1-2.5, the current section develops the three research questions of the thesis. These research questions will be used to guide the research towards achieving the aim of the thesis, as it was stated in Section 1.4: "the thesis aims to provide knowledge of how the configuration and the context of the in-plant materials supply system should be considered when a choice between kitting and continuous supply is made".

Section 2.4 presented and discussed four models of design processes that within previous publications have been suggested to support the design of systems for production, assembly or materials supply. The general approach applied in all of these processes was found promising in relation to the choice between kitting and continuous supply, as a structured process should make it easier to consider all relevant aspects. However, as all of the models had a scope that was much broader than that of in-plant materials supply, the models were not found to be directly useful for supporting the choice between kitting and continuous supply.

As described in Section 2.5, previous publications have suggested models that can be used to predict the relative performance of kitting and continuous supply. In Section 2.5, a review was presented of models suggested by Bozer and McGinnis (1992), Battini et al. (2009), Caputo and Pelagagge (2011) and Limère et al. (2011). As stated in Section 2.5, the model of Battini et al. (2009) does not consider the option of continuous supply, thus making the model difficult to apply directly to the choice between kitting and continuous supply. Each of the models of Bozer and McGinnis (1992), Caputo and Pelagagge (2011) and Limère et al. (2011) is potentially helpful in supporting a choice between kitting and continuous supply. However, as presented in Section 2.5, all of the models also display a number of limitations that restrict their applicability.

The current thesis does not strive to develop quantitative models for comparison of kitting and continuous supply. Instead, using a largely qualitative approach, it addresses the knowledge gaps that exist regarding the two materials feeding principles and the performance that can be expected from using them. In doing so, the thesis also addresses some of the limitations of the models suggested by Bozer and McGinnis

(1992), Battini et al. (2009), Caputo and Pelagagge (2011) and Limère et al. (2011). Accordingly, the thesis considers a larger number of performance areas than any of these models and, in line with the thesis aim presented in Section 1.4, the thesis pays particular attention to how the performance associated with the use of kitting and continuous supply relates to the configuration of the in-plant materials supply system as a whole, as well as to the context of the in-plant materials supply system. These relations were illustrated in Figure 1.1 and are, based on the literature review in Sections 2.1-2.3, illustrated in more detail in Figure 2.6.

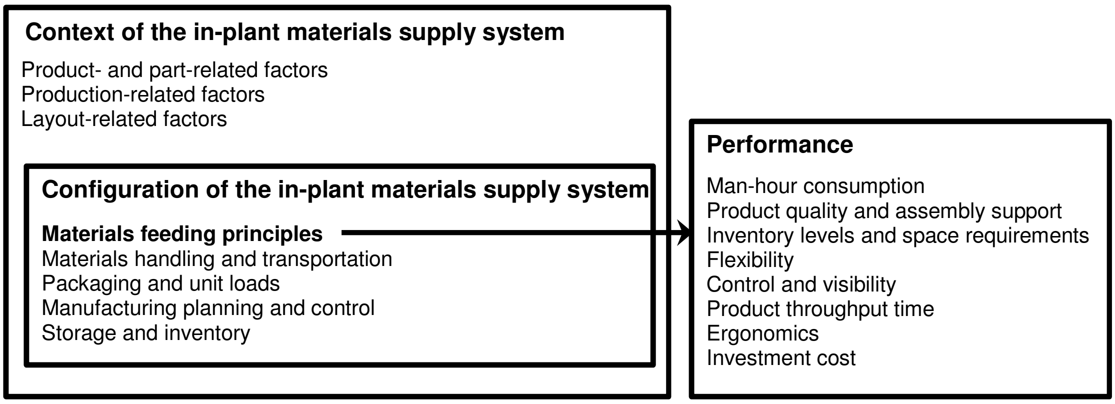


Figure 2.6 *Relation between materials feeding principles and performance, considering the configuration and the context of the in-plant materials supply system.*

When making a choice between kitting and continuous supply, it is important to have an understanding of the full performance impact that can be expected to result from the choice. As presented in Section 2.1, there are a number of elements in an in-plant materials supply system that can affect performance, in addition to the materials feeding principle. Accordingly, when choosing whether to use kitting or continuous supply, an understanding is needed regarding how, specifically, in-plant materials supply utilising each materials feeding principle can be configured, and regarding how the specific configuration can affect performance. However, in many areas, existing publications provide very limited insight regarding how configuration of the in-plant materials supply system, based on either of the two materials feeding principles of kitting and continuous supply, can affect performance.

The three research questions presented in this section address existing knowledge gaps. The first research question seeks, on a general level, to identify how performance, both in assembly and in in-plant materials supply, is related to whether kitting or continuous supply is used. Research questions 2 and 3 delve deeper into how in-plant materials supply systems, based on each materials feeding principle, can be configured and into how performance can be affected by different configurations. The reason for this is that in order to make a comprehensive comparison between kitting and continuous supply, an understanding is needed regarding each of the two materials feeding principles. This, in turn, includes an understanding of how each of the two materials feeding principles can be applied and of how this can affect performance.

2.6.1 Research question 1

When making a choice of whether to use kitting or continuous supply in an industrial application, knowledge is needed of how performance can be affected by this choice. As the performance associated with kitting and continuous supply has close links to both the configuration and the context of the in-plant materials supply systems, there is a need for detailed studies that can identify these links. However, as noted by Hua and Johnson (2010), studies of this type are lacking. Even in relation to the performance areas that have received attention in the previous literature, such as the performance area of man-hour consumption, questions remain regarding the respective benefits and drawbacks associated with kitting and continuous supply, and regarding how they relate to the configuration and to the context of the in-plant materials supply system.

With respect to kitting reducing the time spent fetching parts in assembly, two different contributing aspects associated with kitting have been reported: 1) kitting often enables the parts to be presented in a suitable picking position relative to the assembly object (Jonsson et al., 2004; Neumann et al., 2006; Deechongkit and Srinon, 2009) and 2) with kitting, no time needs to be spent searching for parts (Ding and Puvitharan, 1990; Johansson, 1991; Hua and Johnson, 2010). However, no reports can be found as to the extent of the effects of each of these two aspects. Furthermore, the fact that kitting can often be combined with continuous supply, meaning that an assembly station is supplied with some parts by kitting and others by continuous supply, is scarcely addressed in the existing literature. Bozer and McGinnis (1992) and Hua and Johnson (2010) recognise the possibility of combining kitting and continuous supply, but do not present any evidence as to the effects of such an approach. Caputo and Pelagagge (2011) suggest a method for developing combinations of kitting and continuous supply, but consider only in-plant materials supply performance and not performance in assembly.

Several of the reported drawbacks associated with kitting, compared to continuous supply, are related to the materials supply operations and the preparation of kits. The preparation of kits requires both floor space and time for materials handling (Sellers and Nof, 1986; Bozer and McGinnis, 1992; Hua and Johnson 2010). In cases where the kits are prepared in a separate area that is not directly linked to either storage or the receiving assembly station, the use of kitting will also result in additional transportation (Tamaki and Nof, 1991). However, reports also exist of kitting reducing materials handling (Ding and Puvitharan, 1990; Henderson and Kiran, 1993).

All in all, considerable knowledge gaps exist regarding how performance in both assembly and in-plant materials supply is affected by whether kitting or continuous supply is used.

Research question 1: *How is assembly and in-plant materials supply performance affected by whether kitting or continuous supply is used?*

2.6.2 Research question 2

Considering that many of the potential drawbacks of kitting, compared to continuous supply, are related to the kit preparation, it is of interest to study different approaches for preparing kits. The performance of an in-plant materials supply system based on kitting may differ depending on the more specific configuration of the in-plant materials supply. This should be recognised when a choice between kitting and continuous supply is made.

A number of publications exist addressing kit preparation and/or order picking operations (e.g. Sellers and Nof, 1986; Brynzér and Johansson, 1995; Christmansson et al., 2002; De Koster et al., 2007). However, in addition to the actual kit preparation, several options exist for arranging the materials supply with regards to, e.g. location, storage configuration, load carriers and transport equipment (Sellers and Nof, 1986). These options have received less attention and considerable gaps exist in the current knowledge regarding how materials supply by kitting should be arranged.

There are different options for where the preparation of kits should be performed. In a survey concerning kitting, Sellers and Nof (1986) listed the following potential locations for kit preparation: at a vendor, in an off-site warehouse, in an on-site warehouse, in process or in a staging area. Brynzér and Johansson (1995) bring up the two options of either performing kit preparation in a central location or instead in decentralised areas close to the assembly station. Tamaki and Nof (1991, p. 263) list three main locations for kit preparation: "(1) Off-stores staging area which would be located near and connected to a main storage facility, but not direct function of its operation. (2) Kitting workstation integrated with a main bin storage facility, and (3) In-transit staging area which could be directly next to the assembly area or between production operations". According to Battini et al. (2009), a centralised storage can reduce storage quantities and inventory costs, while a decentralised storage can instead reduce handling costs and increase flexibility, due to the shorter distances and the quicker response from storage to assembly. On the other hand, if the kit preparation is separated from the warehouse, transportation of bins back and forth between the warehouse and the kit preparation area is necessary; something that can be associated with considerable time and cost of handling and is also associated with an additional storage location (Tamaki and Nof, 1991). A further aspect that should be considered is the possibility to arrange a kit preparation area that supports efficiency in the picking operations. As noted by De Koster et al. (2007), the time spent by the order picker is related to the size of the picking area: the smaller the area, the shorter the travel times of the order picker will be.

Research question 2: *When kitting is used, how is in-plant materials supply performance affected by the location of the kit preparation?*

2.6.3 Research question 3

Compared to continuous supply, it seems that kitting often offers the opportunity to present parts to the assembler in more suitable positions relative to the assembly object. However, continuous supply too can be arranged with the aim of achieving a presentation of parts that supports assembly. In order to enable an understanding of how kitting and continuous supply compare, it is hence important to know how well an in-plant materials supply system based on continuous supply can perform, based on demands for space-efficient parts presentation at the assembly stations.

Space-efficient parts presentation by continuous supply can be achieved by the use of small or narrow containers (Wänström and Medbo, 2009; Neumann and Medbo, 2010; Finnsgård et al., 2011) or by the use of minomi, as described in Section 2.1.3, i.e. using no containers at all.

Containers are often an integral part of an in-plant materials supply system and the efficiency of materials handling is then closely linked to the design of the containers and to the interaction between the containers and the handling equipment used (Harit et al., 1997; De Souza et al., 2008). Consequently, a change in the size or type of containers used or, in the case of minomi, an elimination of containers altogether, is likely to have a significant impact on the materials supply operations. As referred to above, some publications exist drawing attention to the impact that the containers used for parts presentation can have on assembly performance (Wänström and Medbo, 2009; Neumann and Medbo, 2010; Finnsgård et al., 2011). However, as discussed by Baudin (2002), the use of small containers, or no containers at all, for presenting parts at the assembly stations may require repacking to be performed in the in-plant materials supply system. Furthermore, the use of small unit loads implies a need to frequently replenish parts by the assembly stations (Baudin, 2004). Thus, if continuous supply is used, it is far from evident how man-hour consumption in in-plant materials supply is affected if there are demands for space efficient parts presentation. Knowledge is needed regarding how the man-hour consumption of the in-plant materials supply is affected by the size and type of unit loads.

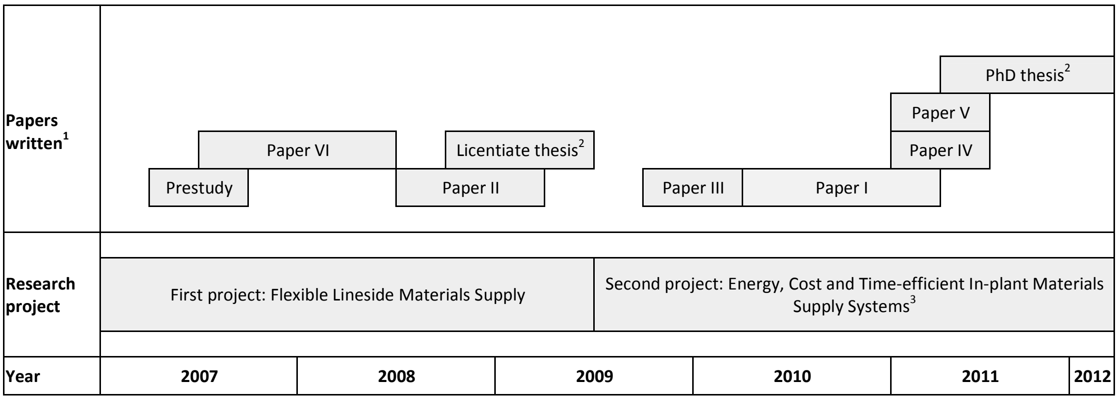
Research question 3: *When continuous supply is used, how is man-hour consumption in in-plant materials supply affected by the size and type of the unit loads?*

3 Methodology

The current chapter presents the research methodology, thereby enabling a critical review of the quality of the research. Section 3.1 presents a description of the research process, providing an overview of the order in which the different studies were performed and describing how the focus of the research evolved during the research process. In Section 3.2, the research strategy is described. Section 3.3 presents the method applied in each of the papers included in the thesis. Finally, Section 3.4 discusses the validity and the reliability of the research.

3.1 Research process

The current thesis is the outcome of five years of research. This section presents a description of the research process during these years. Figure 3.1 presents an overview of the main activities of the research process, and of how they relate in time.



[1] The figure reflects the time spent collecting and analysing data, as well as writing the first version of each paper. All of the papers have been rewritten after the first version, but these processes are not included in the figure.

[2] Illustrates the writing of the cover paper of the thesis.

[3] The project continues until the autumn of 2012.

Figure 3.1 *Overview of the research process. The numbering of the papers is not chronological, but has been made after all papers were written, with the aim of achieving a logical sequence of the papers in the thesis.*

The research has been performed during two successive research projects within the Swedish vehicle assembly industry. The first project, “Flexible Lineside Materials Supply”, was initiated in January 2007 and ended in 2009. The second project, “Energy, Cost and Time-efficient In-plant Materials Supply Systems”, started in 2009 and is planned to end during the fall of 2012. The first project was conducted in cooperation between Chalmers University of Technology (Chalmers) and Saab Automobile (Saab). In the second project too, Chalmers and Saab are among the project partners, but this project further includes Volvo Car Corporation, Volvo Group, Scania and FKG, where FKG is an association representing the automotive supplier industry in Sweden. Both these research projects have a similar focus, both aiming to contribute to a development of high-performing in-plant materials supply systems. None of the projects focuses exclusively on materials feeding principles, but both projects include these principles in their scope.

Throughout his research, starting in January 2007, the author of the current thesis has been employed as an industrial PhD student at Saab. Many of the empirical studies presented in the thesis have been conducted at Saab, especially the studies conducted during the first half of the research process. During the second half of the research process, due to the many project partners in the new research project, the author was provided access to a larger number of companies. Accordingly, during the second half of the research process, several studies were performed at companies other than Saab. All empirical studies, throughout the whole research project, have been conducted at OEM (Original Equipment Manufacturer) assembly plants within the Swedish automotive industry.

The research process started with a pre-study aiming to establish the current state of both the existing literature and of the Swedish vehicle assembly industry (presented in Hanson and Johansson, 2007). The purpose of this study was to identify areas in particular need of further development and to provide a foundation for further research. The study was based both on the existing research literature and on interviews performed within Saab, Volvo Car Corporation, Volvo Trucks and Scania. One of the findings of the pre-study was that the area of materials feeding principles was in need of further development. Based both on the interviews in industry and on the literature review, it was evident that considerable knowledge gaps existed within this area. Other areas of interest were, however, also found in the pre-study and the focus of the research was not yet directed exclusively towards materials feeding principles, but the research had a broad scope covering the whole in-plant materials supply system.

At the time when the research was initiated, in the beginning of 2007, there was much interest within Saab in the in-plant materials supply concept of "minomi", through which parts can be supplied without packaging. Drawing on the interest within Saab, empirical studies were initiated, focusing on applications of minomi within the Saab assembly plant. These studies were included in paper VI of the thesis. (The numbering of the papers is not chronological, but has instead been made after all the papers were written, with the aim of achieving a logical sequence of the papers in the thesis.)

Starting in 2008, the author of the thesis noticed a considerable and growing interest in kitting within Saab. Soon, this interest was found to exist within other companies also. It was as a result of this interest, which manifested in a number of kitting introductions within industry, that the focus of the research presented in the current thesis was finally directed towards materials feeding principles. In 2008, and still today, continuous supply was the dominating materials feeding principle among the Swedish OEMs in the vehicle assembly industry. The existence of kitting was however well known and the principle was used within several of the companies, albeit to a small extent. The fact that kitting was far from being a new concept, having been used in industry for decades, made it surprising to discover both the knowledge gaps within industry and the scarcity of literature on the topic.

Through 2008-2010, kitting replaced continuous supply in a number of in-plant materials flows among the Swedish vehicle assembly OEMs. Registering the effects of some of these introductions, and comparing kitting with continuous supply, a number of case studies were conducted in this time period, and are presented in papers I and II of the thesis. Complementing the case studies, an experiment was performed in 2009, comparing how parts presentation by kitting and continuous supply affected the time for materials handling at an assembly station. The results of this experiment are presented in paper III of the thesis.

In addition to the papers comparing the effects of using kitting and continuous supply (papers I-III), it was found that more knowledge was needed about the specific design of materials supply based on each of the principles of kitting and continuous supply. Paper VI was found to already provide a contribution in this respect, as it studies a concept that enables in-plant materials supply by continuous supply to be arranged to achieve space-efficient parts presentation, which is one of the major advantages that is normally associated with kitting. Complementing paper VI, which focused on the relatively narrow concept of minomi, another study was made, focusing on continuous supply by more traditional unit loads and the effects that the size of the unit loads had on the man-hour consumption of the in-plant materials supply. This study is presented in paper V of the thesis. In addition to papers V and VI, focusing on continuous supply, it was found that further knowledge was needed about in-plant materials supply by kitting. In this context, the location of the kit preparation was found to be of central importance. Accordingly, a study was made, presented in paper IV, with the aim of determining how the location of the kit preparation affects the performance of the in-plant materials supply.

In 2009, the author of the thesis presented his licentiate thesis, based on the results of his research so far. The licentiate thesis included preliminary versions of papers II and VI of the current thesis, as well as a paper based on the pre-study that was conducted in 2007 (Hanson and Johansson, 2007). In the spring of 2011, the writing started of the cover paper of the current thesis.

Table 3.1 presents the responsibilities that the author of the thesis had in each of the six papers that are included in the thesis. In the writing of all of these papers, the author of the thesis had the role of first author.

Table 3.1 *Characteristics of the different papers and the studies they are based on*

Paper	First author	Co-author 1	Co-author 2	Responsibility of the first author
I	Hanson, R.	Brolin, A.	-	The first author had principal responsibility for planning the study, for collecting and analysing the data and for writing the paper.
II	Hanson, R.	Medbo, L.	-	The two authors jointly planned the study and collected the data. The first author had principal responsibility for analysing the data and for writing the paper.
III	Hanson, R.	Medbo, L.	Medbo, P.	The first author had principal responsibility for planning the study, for collecting the data and for writing the paper. He participated in the analysis of the data, but did not have principal responsibility for the quantitative analysis.
IV	Hanson, R.	Johansson, M.I.	Medbo, L.	The first author had principal responsibility for planning the study, for collecting and analysing the data and for writing the paper.
V	Hanson, R.	Finnsgård, C.	-	The two authors jointly planned the study and performed the analysis. The first author participated in the data collection, but did not have principal responsibility for it. The first author was responsible for writing the paper.
VI	Hanson, R.	-	-	The first (and sole) author performed all tasks involved in writing the paper.

3.2 Research strategy

Five of the six papers included in the thesis are based on case studies, whereas the sixth (paper III) is based on an experiment that was set up at an automobile assembly plant, with conditions that were meant to be as close as possible to actual assembly conditions.

According to Yin (2009), "a case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". Case studies are useful for creating understanding of single settings, even under dynamic circumstances (Eisenhardt, 1989). Because of their ability to capture complex systems with a high level of detail, as discussed by Hill et al. (1999), case studies have been found useful in the research process of the current thesis.

For all of the papers included in the thesis, literature studies have been used, firstly, to identify a research gap and to formulate the aim of each of the papers and, secondly, to support the analysis in the respective paper. Accordingly, the studies of the thesis all have a clear starting point in the existing literature. Based on the literature, an analysis model has been developed for each of the papers, where a preliminary view is presented of the respective study object. The empirical studies are used partly to confirm the relations in the analysis model and, partly, to expand on them.

Many of the case studies presented in the thesis have similarities with experiments and can be seen as "natural experiments" (Shadish et al., 2002). This applies to the case studies presented in papers I, II, V and VI. In each of these case studies, comparisons are made between two situations: before and after some form of change to the system, e.g. an introduction of kitting. Accordingly, even though the researcher has not had full control of the system, the system has been altered in a manner that corresponds to the focus of the respective study. For example, paper I presents two cases, where kitting has been introduced to replace continuous supply. In each of the two cases, the in-plant materials supply and the assembly were studied both before and after the introduction of kitting, hence enabling comparison of the two materials feeding principles. Two of the case studies in question, case studies 6.2 and 6.3 of paper VI, differ from the rest, in that they compare an actual situation to a hypothetical situation, rather than comparing two actual situations.

The changes that have been made to the studied systems in papers I, II, V and VI have all been initiated by the respective company. As argued by Hill et al. (1999), it can be beneficial to undertake research in response to an opportunity within an organisation, rather than based on a research agenda that is not linked to practical application. "Opportunity-driven" research like this is likely to have a strong industrial relevance and is often accompanied by access to relevant data (Hill et al., 1999).

Within the research project, it has not been possible to perform full experiments with actual in-plant materials supply systems, as these systems have not been within the author's control. However, one experiment, presented in paper III, has been performed in a controlled environment. The experiment focuses on a limited set of aspects, but provides a valuable complement to the other studies. A main advantage of experiments is the level of control that the researcher can exert, which can enhance internal validity of the study (Bryman and Bell, 2011).

3.3 Methods applied in each of the papers

As the thesis is a compilation of six research papers, each of these papers plays an important role in relation to the thesis as a whole. The papers complement each other in relation to the aim and the research questions of the thesis, but each of the papers also provides a contribution of its own and is based on one or several studies of its own. The current section presents the methods applied in each of the six papers included in the thesis. An overview of the characteristics of the different papers and of the studies they are based on is presented in Table 3.2.

Table 3.2 *Characteristics of the different papers and the studies they are based on*

	Purpose	Research design	Sources of empirical data
Paper I	To provide insight into how the relative effects of using kitting and continuous supply arise	Multiple case study (two cases: 1.1 & 1.2)	Direct observations, interviews, internal company documentation and video recordings
Paper II	To determine what impact the proportion of parts supplied by kitting has on the time spent by the assembler fetching parts	Multiple case study (four cases: 2.1-2.4)	Direct observations and video recordings
Paper III	To determine how kitting, compared to continuous supply, affects the time spent by the assembler fetching parts	Experiment under controlled conditions	Video recordings
Paper IV	To determine how the location of kit preparation affects in-plant materials supply performance	Multiple case study (three cases: 4.1-4.3)	Direct observations, interviews and internal company documentation
Paper V	To explore how the man-hour consumption of the in-plant materials supply is affected by the size of the unit loads used	Single case study (case 5.1)	Direct observations, interviews and internal company documentation
Paper VI	To identify the effects of using minomi in materials supply within an assembly plant	Multiple case study (three cases: 6.1-6.3)	Direct observations, interviews, internal company documentation and video recordings

In each of the papers that are based on more than one case study, the different cases are presented as "case 1", "case 2", etc. In the thesis, in order to distinguish between the different cases of the different papers, the numbering of the cases has been modified. Accordingly, the different cases of the thesis are here numbered, partly, based on which paper they are presented in and, partly, based on the numbering they have in their respective papers. Accordingly, case 1 of paper I is here numbered case 1.1, case 1 of paper II is numbered 2.1, etc.

Some of the cases studied in the different papers are based on the same, or to some extent overlapping, systems: cases 1.1 (in paper I), 2.2 (in paper II) and 4.1 (in paper IV) are from the same assembly line within the Saab assembly plant. Nevertheless, in the thesis, they are considered to be separate cases, as they display a number of differences. Firstly, the focus of the studies in the different papers differ and, secondly, data have been collected on different occasions for the different studies, meaning that the assembly operations, and the in-plant materials supply supporting them, have undergone changes between the different studies.

3.3.1 Methods applied in paper I

Paper I has the aim of providing insight into how the relative effects of using kitting and continuous supply arise. Thereby, the paper contributes to answering research question 1 of the thesis. The paper takes its point of departure in the existing literature and in the relative effects of using kitting and continuous supply stated there. To achieve the aim of the paper, two different cases have been selected, case 1.1 and case 1.2, in each of which it has been possible to study both kitting and continuous supply in the same production environment. The two cases complement each other in that they display a number of differences in terms of how the in-plant materials supply and the parts presentation by kitting were arranged. In case 1.1, travelling kits were introduced, that together with the assembly objects moved along the assembly line, containing parts for several assembly stations. In contrast, the kits that were introduced in case 1.2 were stationary, supporting only one assembly station each. Furthermore, the kits introduced in case 1.1 had formal structures with a fixed position for each part, whereas in case 1.2, no fixed positions were used and the structure of the kits could vary, as it was up to the picker to decide how the parts should be placed.

To some extent, there were also differences between the two cases in the motives for introducing kitting and in the choices of which parts to supply by kitting.

Data were collected by means of direct observations, interviews and internal company documentation. In both cases, data were collected both before and after kitting was introduced. Within each of the two case companies, interviews were performed with personnel who had been involved in making the decisions to introduce kitting, with personnel who had been involved in performing the introductions, as well as with assemblers and operators responsible for the kit preparation. (In case 1.1, the assemblers were themselves responsible for the kit preparation.) The interviews were semi-structured and performed face to face. Complementing the face-to-face interviews, some additional questions were also asked over the telephone and via email.

In case study 1.2, video recordings were made both before and after the introduction of kitting, enabling a detailed comparison of the man-hour consumption. For two of the four assembly stations where kitting was introduced, the assembly, the kit preparation and the transportation of kits were video recorded and analysed according to an approach similar to that of Engström and Medbo (1997), in which manual assembly work is recorded and analysed using a computer synchronised with the video recorder. With this approach, the initial analyses of the recordings result in a categorisation of the recorded work into predefined activities, in which the time consumption of each activity is registered. In case study 1.2, the assembly, the kit preparation and the transportation of kits associated with two commonly occurring engine variants were studied and analysed. The same engine variants were in focus before as after the introduction of kitting. At the two assembly stations studied, only the activities associated with fetching parts (turning, walking, grasping parts, etc.) were analysed, as these were the activities where the difference between kitting and continuous supply were anticipated to be the greatest. All activities associated with preparing the kits and transporting them to assembly were analysed.

3.3.2 Methods applied in paper II

Paper II studies the combination of kitting and continuous supply, where some parts are supplied by kitting and others by continuous supply. Focusing on the time spent by the assembler fetching parts in manual assembly, the aim of the paper is to determine what the impact is of the proportion of parts supplied by kitting. The paper contributes to answering research question 1 of the thesis.

Based on a literature review, the paper first identifies, on a general level, how parts presentation by kitting, compared to by continuous supply, can affect the time spent fetching parts in manual assembly. Four cases are then presented where the use of kitting can be compared to the use of continuous supply. In one of the cases, case 2.1, a transition was made from kitting to continuous supply, whereas in each of the other three cases, case 2.2, case 2.3a and case 2.3b, a transition was made from continuous supply to kitting. In each of the four cases, it was possible to study assembly operations in more or less the same settings, but with different materials feeding principles. This resulted in an excellent basis for comparison between the effects of using kitting and continuous supply on the time spent fetching parts. As the paper further seeks to identify the impact of the proportion of parts included in the kit, the cases studied were also chosen so that they among themselves displayed differences in this respect. Accordingly, the kits used in case 2.1 included 100% of the parts, the kits in case 2.2 included 50% of the parts, the kits in case 2.3a included 22% of the parts and the kits in case 2.3b included 10% of the parts. The parts that were not presented in kits were instead presented in component racks.

In all four cases, the work of the assemblers was video recorded and analysed. An approach was used similar to that of Engström and Medbo (1997), as described in relation to paper I in 3.3.1. In the video analyses, the activities that the work was divided into were the same as the ones used by Jonsson et al. (2004) and accordingly included the activities *direct assembly work*, *fetch small materials*, *fetch medium-sized materials* and *fetch large materials*. In the paper, the time spent fetching medium-sized and large materials constitutes the basis for the figures presented and analysed. Included in *fetching* are all activities performed by the assembler in association with getting a part from where it is presented to where it is to be assembled, i.e. turning, walking, reaching out, grasping and walking back to the assembly object.

Not all activities performed by the assemblers are included in the paper, as some are not relevant to the aim of the paper. Notable is the exclusion of the activity "fetch small materials", included in the original analysis of the video recordings. The picking of "small materials", a term that mainly denotes fasteners, such as screws and bolts, differed from the picking of the other, larger parts. In all of the cases, small materials were supplied by continuous supply, both in the kitting and non-kitting situations. Furthermore, unlike the larger parts, the small materials were often picked several at a time, i.e. in one movement of the assembler. In the video analyses it was therefore difficult to determine how many parts were actually picked in these activities. Accordingly, in the presentation of the case studies in this paper, where the percentage of parts included in the kits is listed, this figure does not consider small materials.

As each of the case studies includes two different situations, one where kitting was used and one where it was not, the assembly work was recorded at two occasions for each case. Each recording was performed during a workday chosen at random. Table 3.3 shows the number of assembly cycles recorded for each of the case studies. In line with the purpose of the paper, the analysis is based on the average fetching times recorded in each of the cases. In order to enable an understanding of the origin of these fetching times, the analysis further considers the number of parts fetched from both component racks and kits, as well as the number of times the assembler visited the component racks, as this was closely associated with the walking distances of the assembler.

In two of the cases studied, cases 3a and 3b, the length of the assembly stations was reduced at the same time that kitting was introduced. This was not related only to the introduction of kitting, but also to a simultaneous reduction in assembly cycle time. However, the introduction of kitting helped in enabling the reduction of the length of the assembly stations, as the component racks were reduced when parts were presented in kits instead of in component racks. In both of the cases, assembly was performed along a continuously moving assembly line. By the company, the reduction in assembly station length was considered to impact the work of the assemblers mainly by decreasing the walking distance preceding each work cycle: when the assembler returns to the start of the assembly station, after having followed the preceding assembly object to the end of the assembly station. The time spent by the assemblers walking back to the start of the assembly station at the beginning of each assembly cycle was not included in the analyses of the paper, which focused only on the time spent fetching parts, and the potential effects of the change in assembly station length should therefore be negligible in relation to the aim of the paper.

Table 3.3 *Number of assembly cycles recorded and analysed in each case study of paper II*

		Number of assembly cycles recorded
Case study 2.1	Kitting	9
	No kitting	5
Case study 2.2	Kitting	13
	No kitting	10
Case study 2.3a	Kitting	2
	No kitting	2
Case study 2.3b	Kitting	2
	No kitting	9

3.3.3 Methods applied in paper III

Paper III contributes to answering research question 1 of the thesis and has the aim of determining how kitting, compared to continuous supply, affects the time spent by the assembler fetching parts in manual assembly. The paper is based on an experiment set up at the Saab assembly plant. However, the experiment was not conducted during regular assembly, but in an environment where the conditions of the experiment could be controlled. It was designed in collaboration with production engineers from the company, so that the conditions in the experiment would be as close as possible to actual assembly conditions, thereby increasing the validity of the experimental setup and the relevance and industrial applicability of the results.

The experiment revolved around the assembly of a pedal unit from an obsolete car model that is no longer in production. In the experiment, experienced automobile assemblers were studied and video recorded as they performed the same assembly operations in a number of different configurations, where each configuration consisted of a different arrangement in terms of how parts were presented. From the video recordings, the time spent fetching parts could be measured and analysed.

From a literature review, four aspects of parts presentation were identified that were of potential relevance to the time spent by the assembler fetching parts in manual assembly. The first aspect concerns the materials feeding principle, i.e. whether the parts were presented through kitting, where all parts for one pedal unit were included in each kit, or continuous supply, with each part number in a separate container. The second aspect concerns whether the number of part variants was small or large. “Small” and “large” were in the experiment set to two and four part variants, respectively. This aspect was relevant only to the continuous supply configurations. Since the kits contained only the correct part variants, the kitting configurations did not require the assembler to be concerned with the choosing of the part variant. The third aspect concerns the way in which picking information was provided to the assembler – either through light indicators, showing the assembler which part variant to choose, or through printed product specifications for each pedal unit. Like the second aspect, this information is only relevant in the continuous supply configurations. Finally, the fourth aspect concerns whether the parts were presented by the assembly object, i.e. the pedal unit being assembled, or opposite to it.

The four aspects of parts presentation were combined into ten configurations, as illustrated in Table 3.4.

Table 3.4 *The different configurations used in the experiment of paper III*

Configuration #	Feeding principle	Number of part variants	Picking information	Position of parts
1	Cont. supply	Small	Printed	By assembly object
2	Cont. supply	Large	Printed	By assembly object
3	Cont. supply	Small	Printed	Opposite to assembly object
4	Cont. supply	Large	Printed	Opposite to assembly object
5	Cont. supply	Small	Light indicators	By assembly object
6	Cont. supply	Large	Light indicators	By assembly object
7	Cont. supply	Small	Light indicators	Opposite to assembly object
8	Cont. supply	Large	Light indicators	Opposite to assembly object
9	Kitting	-	-	By assembly object
10	Kitting	-	-	Opposite to assembly object

Before the actual experiment was conducted, a pilot study was performed with the purpose of eliminating potential sources of bias in the final design of the experiment. In the pilot study, three experienced automobile assemblers, none of whom took part in the final experiment, assembled a number of pedal units of the same type as in the final experiment. Three of the four aspects of the parts presentation that were varied in the final experiment were also varied in the pilot study; only the use of light indicators was not included in the pilot study. A finding from the pilot study was that learning effects were significant when the assemblers were first introduced to the assembly of the pedal units, but that after about 20-30 minutes, equivalent to 7-10 assembly cycles, the learning effects had worn off and cycle times were stable. Based on this, each of the assemblers in the final experiment underwent one hour of training before participating. To further eliminate potential effects of learning, or indeed of other unwanted potential influences, each of the assemblers in the final experiment went through the ten different configurations in an individual, randomised sequence.

In the final experiment, three assemblers (not the ones taking part in the pilot study) each performed seven cycles of the assembly operations (i.e. they each assembled seven pedal units) in each of the ten different configurations. The assemblers that participated in the experiment were male and 47, 46 and 34 years old, respectively. They were all experienced and had been working as automobile assemblers at Saab for 29, 28 and 14 years, respectively. The choice to use seven assembly cycles for each assembler was based on results from the pilot study, which indicated that the variance would be relatively low with this number of cycles. Moreover, practical restrictions in terms of availability of the assemblers made it difficult to include more cycles than this.

In the configurations where continuous supply was used, each part number was presented in a separate container in a component rack, whereas, in the configurations where kitting was used, all parts for each assembly object were presented together in one container. In order to constitute a competitive alternative to kitting, the parts presentation in component racks was, in the experiment, designed to support time-efficient picking of parts. Accordingly, in line with the results of Wänström and

Medbo (2009), Neumann and Medbo (2010) and Finnsgård et al. (2011), the parts in component racks were presented in narrow and shallow containers from which parts were easy to pick. When the parts were presented opposite to the assembly object, the distance between the assembly object and the parts was one metre, decided together with the Saab production engineers, who found this to be a typical distance for this type of assembly. To facilitate understanding of how the parts presentation was arranged in the experiment, Figure 3.2 includes pictures of each of the four combinations of component racks by the assembly object, component racks opposite to the assembly object, kit by the assembly object and kit opposite to the assembly object.

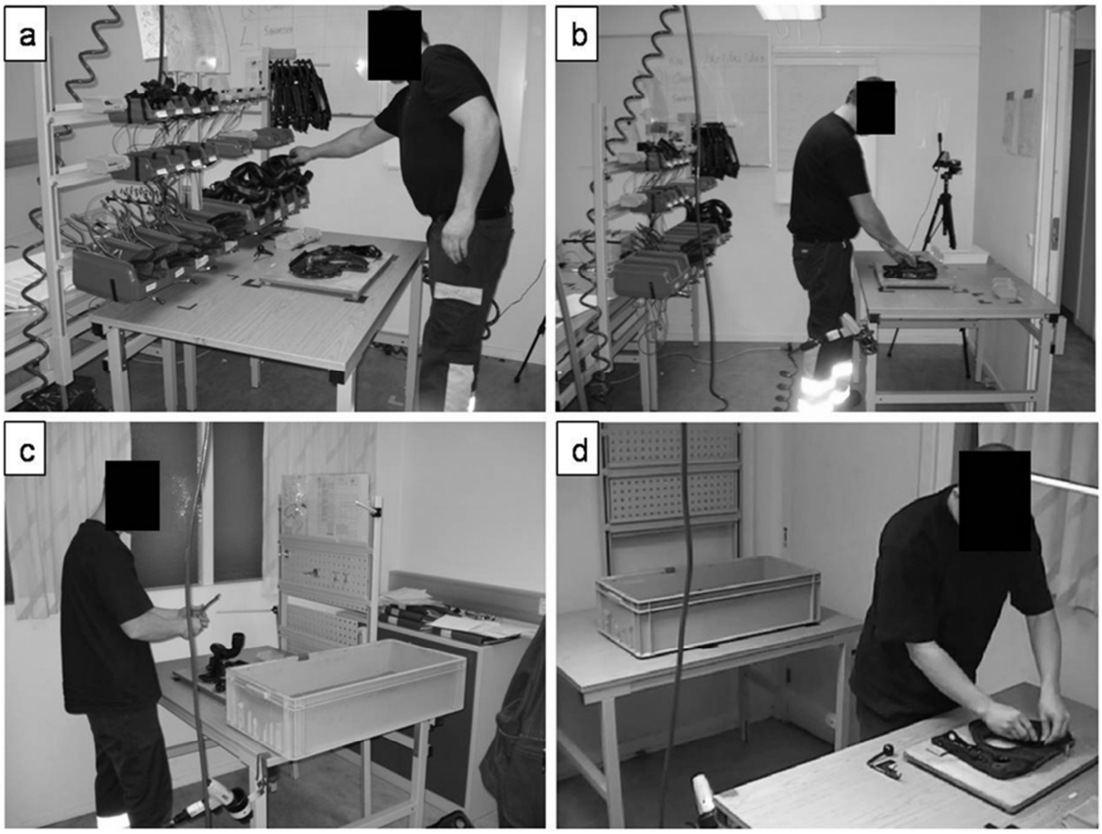


Figure 3.2 *a) Component racks by assembly object (configurations 1, 2, 5, 6), b) component racks opposite to assembly object (configurations 3, 4, 7, 8), c) kit by assembly object (configuration 9) and d) kit opposite to assembly object (configuration 10)*

The original pedal unit that was used as a basis for the experiment consisted of 17 parts of 13 different part numbers and did not contain any parts with more than one variant. However, as some of the advantages of parts presentation in kits were believed to be associated with the existence of part variants, a number of part variants were created as part of the experiment design. Out of the 13 part numbers of which the pedal unit originally consisted, five were chosen and expanded into several part variants (i.e. they were each expanded into several part numbers) by the use of evident colour markings. Depending on configuration, two or four variants were used for each of the five parts, which meant that up to 28 part numbers were used in the different configurations of the experiment. Figure 3.3 shows an overview of the parts included in the pedal unit that was assembled during the experiment and Table 3.5 displays a list of these parts, showing how many were assembled in each pedal unit and which of the parts had more than one variant. The part variants differed in terms of appearance (i.e. colour) but not in terms of how they were assembled. Accordingly, the introduction of part variants made it necessary for the assembler to identify, pick and assemble the right part variants for each pedal unit, but did not cause any changes to the actual assembly operations.

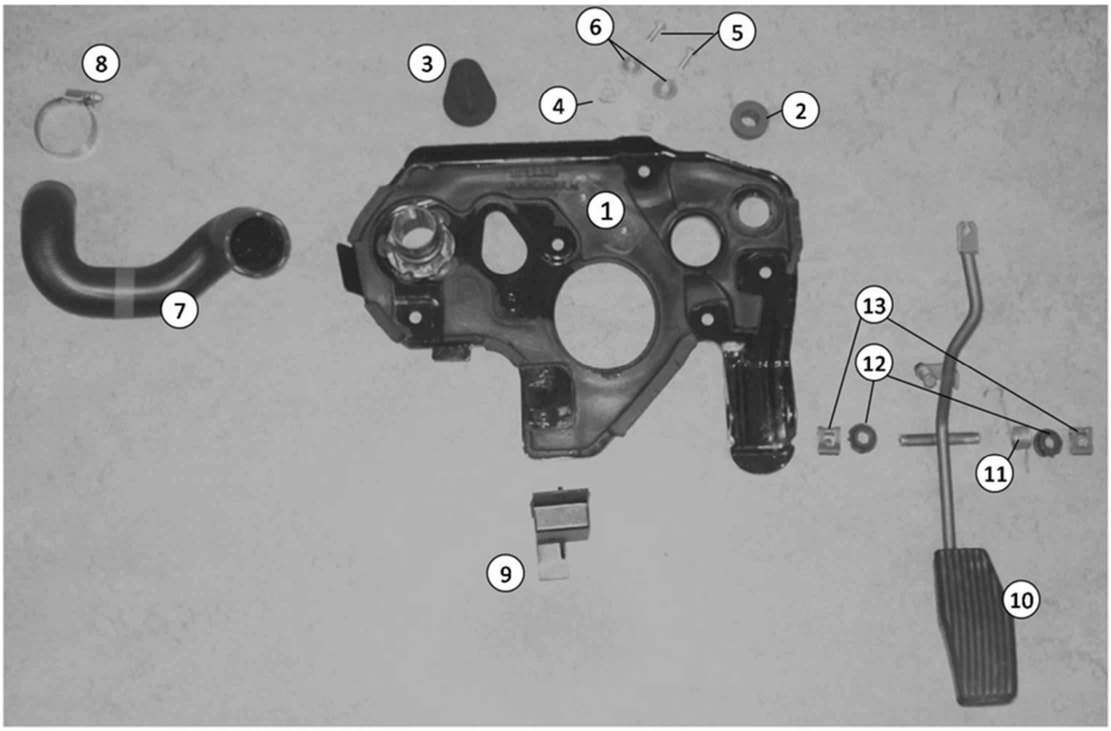


Figure 3.3 *Overview of the different parts included in the experiment of paper III, together forming a pedal unit*

Table 3.5 *List of the parts included in one pedal unit*

	Number of parts in each pedal unit	Number of part variants
Part 1	1	1
Part 2	1	1
Part 3	1	1
Part 4	1	2 or 4
Part 5	2	1
Part 6	2	1
Part 7	1	2 or 4
Part 8	1	1
Part 9	1	2 or 4
Part 10	1	2 or 4
Part 11	1	2 or 4
Part 12	2	1
Part 13	2	1

The video recordings of each of the assembly cycles were analysed using an approach similar to that of Engström and Medbo (1997), as described in relation to paper I in Section 3.3.1. Through the analysis of the video recordings, the time spent by the assembler on a number of predefined activities was determined for each of the assembly cycles of the experiment. These predetermined activities were: 1) assembly, 2) fetching and handling tools, 3) fetching parts and 4) other, where "other" included all activities that could not be referred to as any of the first four activities, e.g. handling product specification sheets or moving finished pedal units. It is to be noted that in assembly along a continuously moving assembly line, the two latter activities (i.e. handling product specification sheets or moving finished pedal units) are not likely to occur, as both the product and, most likely, the product specifications are moved automatically. As described below, these last two activities were not in focus in the analysis presented in paper III, which focuses on the time spent fetching parts.

In order to conclude if there was a significant difference between the time spent fetching parts in the different configurations and, if so, to quantify this difference, an ANOVA was conducted. In the ANOVA, the time spent fetching parts in each of the ten configurations was compared. Another ANOVA was conducted comparing the time spent on actual assembly in each of the ten configurations. This latter analysis was performed in order to determine whether the parts presentation had any additional effects that had not been anticipated. Accordingly, no significant difference was expected here.

The ANOVAs were carried out using SPSS software (www.spss.com), analysing both the time for fetching parts and the time for assembly. To identify differences over all configurations, the Tamhane's T2 *post hoc* test was used after testing for variance homogeneity (Levene statistics, $p < 0.05$). Since the Levene statistics rejected the assumption of equal variance, both for the time for fetching parts and for the time for assembling, Tamhane's T2 *post hoc* test was used. Note that ANOVA is robust to the violation of equal variances in this study since the ten configurations compared are of equal size (i.e. number of observations). For a more thorough discussion on ANOVA and *post hoc* test, see Hair et al. (2010).

3.3.4 Methods applied in paper IV

Paper IV is in the thesis used to answer research question 2 and, accordingly, aims to determine how the location of kit preparation affects in-plant materials supply performance. To achieve this, three different cases were identified, where principally different locations for kit preparation could be studied and compared. The three cases were from three different assembly plants, each from a different OEM within the Swedish automotive industry. Each of the case studies focuses on the in-plant materials supply supporting the assembly operations within a limited section of the respective assembly plant. In all of the assembly plants, production was performed according to build-to-order principles. The products were relatively standardised in terms of their basic architecture, but there was a large amount of different part numbers that could be assembled into different product variants. The three cases differed from each other by having three fundamentally different locations for kit preparation: (1) at the assembly line, (2) in the main storage of the assembly plant and (3) in a separate kit preparation area in-between storage and assembly line. Table 3.6 displays the basic characteristics of each of the cases.

Table 3.6 *Basic characteristics of the three cases of paper IV*

	Case 4.1	**Case 4.2**	**Case 4.3**
Product assembled:	Car dashboard sub-assembly	Truck cab	Car (parts of final assembly)
Assembly cycle time:	2 minutes	3.3 minutes	10.2 minutes
Location of kit preparation:	In a separate kit preparation area	At the assembly line	In the main storage

Based on a literature review, a theoretical framework is developed that is used for analysing and comparing the three cases that are studied in the paper. The analysis of the cases is qualitative in nature. With this approach, the paper takes the characteristics of each case into account and identifies those aspects that are related to the location of the kit preparation. In order to enrich the descriptions of each of the cases, some quantitative data are presented in the paper, but these data are not in focus in the analysis. From each of the three cases, data were collected by means of direct observations, interviews and documentation from the respective company. The interviews were semi-structured and performed face to face. Complementing the face-to-face interviews, some additional questions were asked over the telephone and via email. The data collection in each of the cases focused on the amount of transportation, the inventory levels and space requirements, the potential for visual control, the flexibility, the efficiency of the kit preparation, the quality of the kits and the responsiveness to quality deficiencies, and the ability to achieve continuous improvement.

3.3.5 Methods applied in paper V

Addressing research question 3 of the thesis, paper V studies how the man-hour consumption of the in-plant materials supply is affected by the size of unit loads, when continuous supply is used. The paper is based on a case study from a company within the automotive industry. The case includes three assembly lines and the in-plant materials supply supporting them. In the case, a comprehensive redesign was made of the in-plant materials supply and parts presentation. A main aim of the redesign was to achieve compact assembly stations, which meant that for a large proportion of the parts, the size of the unit loads was considerably reduced, which, in turn, meant that the in-plant materials supply had to be redesigned.

The analysis of the case study utilises a frame of reference, derived from the literature. In line with the frame of reference, the paper considers not only the size of the unit loads, but also the types of unit loads used, the types of handling equipment and the principal configuration of the material flows, as all of these aspects are relevant in relation to the man-hour consumption of the in-plant materials supply system.

The case study is based on data from both before and after the redesign of the in-plant materials supply and compares both the configuration and the efficiency of the in-plant materials supply. Data were collected by means of direct observations, interviews and internal company documentation.

3.3.6 Methods applied in paper VI

Paper VI studies the concept of minomi, which can be used in in-plant materials supply to assembly stations, either both for handling and presenting parts, or only for presenting them. The aim of the paper is to identify the effects of using minomi in materials supply within an assembly plant. Furthermore, the paper identifies relations between these effects and the characteristics of the situations where minomi is applied. In the thesis, the paper contributes to answering research question 3.

The paper is based on three case studies from Saab and focuses on the effects the use of minomi has in terms of man-hour consumption and occupied space in the component racks where parts are presented at the receiving assembly station. In the paper, the man-hour consumption is considered in both the materials supply operations and the assembly operations.

The effects of using minomi may differ depending on the characteristics of the material flows and their surroundings. Accordingly, based on a literature review, the paper first identifies categories of characteristics that are of potential relevance to the effects of using minomi. These categories are then used for structuring both the case studies and the results of the paper. The three categories of characteristics, identified in the paper, are part characteristics, characteristics of the receiving assembly station and characteristics of handling and storage. These are represented in Figure 3.4.

"Part characteristics" include size, shape and weight of the parts, as well as sensitivity to damage. "Characteristics of the receiving assembly station" include the space available to present parts and how the parts are picked or unloaded from the unit load. "Characteristics of handling and storage" include how handling (including e.g. picking, sorting and transportation) and storage are performed. This includes which equipment is used (if any), handling quantities and handling distances.

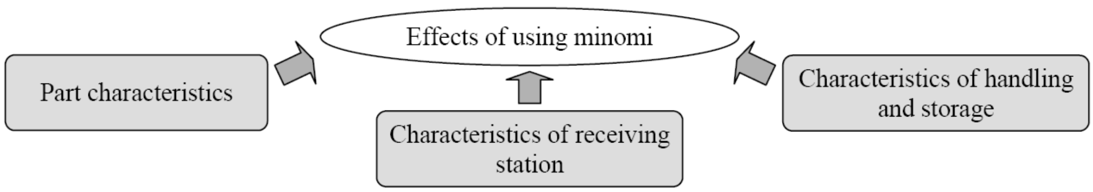


Figure 3.4 *Characteristics of potential relevance to the effects of using minomi*

The three case studies of the paper display a number of important differences, both in terms of the type of minomi solution (with and without part carriers) and in terms of the characteristics of the material flows and their surroundings (i.e. part characteristics, characteristics of the receiving assembly station and characteristics of handling and storage). Therefore, they complement each other well in relation to the aim of the paper.

Each of the case studies is based on an actual material flow, for which both a minomi supply solution and a supply solution with containers are studied. In case 6.1, an actual minomi solution was introduced by Saab and could be compared to the previous solution with containers. In cases 6.2 and 6.3, no minomi systems are in place, but at the time that the studies were performed, plans existed within Saab to introduce minomi here, as a number of benefits were anticipated by the company. Investigations were, therefore, made within the company regarding the effects of using minomi in these cases. Case studies 6.2 and 6.3 of the paper were performed together with the company as part of these investigations. For cases 6.2 and 6.3, the case studies therefore describe the existing supply systems with containers and compare these to potential minomi systems, whose performance has been predicted and calculated.

As already stated, the effects of using minomi are studied in terms of man-hour consumption in the materials supply operations and in the assembly operations, as well as in terms of the occupied space in the component racks at the receiving assembly stations. As all three dimensions of space (in this paper denoted length, height and depth) are not necessarily equally important in this context, the effects in terms of changes in occupied space in the component racks are presented in each of the case studies as three separate measures of distance, one for each dimension, rather than as one measure of volume. As seen in Figure 3.5, the occupied *length* of the component racks is in the paper measured as a horizontal distance along the side facing the assembly station, the occupied *height* of the component racks is measured as a vertical distance and the occupied *depth* is measured as a horizontal distance perpendicular to the side of the component racks facing the assembly station. Table 3.7 presents an overview of how the performance in terms of man-hour consumption was determined in each of the three case studies. The man-hour consumption was in each of the case studies determined as *average* man-hour consumption, both where authentic data were analysed and where the performance was determined through calculation.

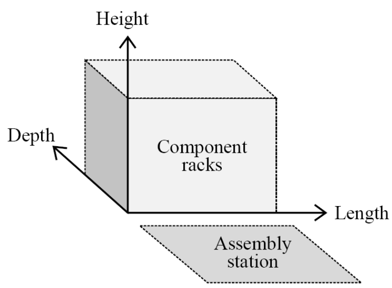


Figure 3.5 *The different dimensions of the space in the component racks – presented in relation to the assembly station*

For case 6.1, a careful study was made both before and after minomi was introduced. The assembly operations were video recorded and analysed according to an approach described and utilised by Engström and Medbo (1997) (see Section 3.3.1). The man-hour consumption in the material supply operations was established in case study 6.1 through studies of archival data, which had been registered within the company. In case studies 6.2 and 6.3, the man-hour consumption of the materials supply operations in the non-minomi setup was established from archival data from the company, the same way as in case study 6.1. Since no data were available for the corresponding man-hour consumption in the minomi setup of these cases, this man-hour consumption was calculated instead. As a basis for the calculations, data from the company were used, which reflected the speed of the delivery units, time for manual handling in the deliveries, etc. Travel distances within the plant were measured.

The man-hour consumption of the operators involved in the assembly operations was not analysed in detail for cases 6.2 or 6.3. Instead, the effects were easy to predict; in case 6.2, the manual assembly operations would be completely eliminated, whereas there would be no considerable effects at all in case 6.3, as the parts presentation and the handling performed by the assembly operator would not change in this case.

Table 3.7 *How the man-hour consumption was determined in each of the case studies of paper VI*

	Assembly operations		Materials supply operations	
	Non-minomi setup	**Minomi setup**	**Non-minomi setup**	**Minomi setup**
Case study 6.1	Actual data available, operations video recorded and analysed	Actual data available, operations video recorded and analysed	Actual data available – collected from archival records	Actual data available – collected from archival records
Case study 6.2	Actual data available, operations observed and analysed	No actual data available, effects predicted	Actual data available – collected from archival records	No actual data available, effects calculated
Case study 6.3	Actual data available, operations observed and analysed	No actual data available, effects predicted	Actual data available – collected from archival records	No actual data available, effects calculated

3.4 Validity and reliability

In order to evaluate the quality of the thesis, the aspects of validity and reliability of the research are crucial to consider. As stated by Riege (2003, p. 76), "a discussion as to how the chosen research methodology can achieve validity and reliability forms an integral part of any rigorous research effort". The current section discusses the validity and reliability of the research studies on which the thesis is based.

The validity of a study concerns the extent to which the measure(s) used in the study corresponds to the object of study, whereas the reliability of the study concerns the consistency of the measure(s) (Hair et al., 2010). In relation to case study research, which is the main research strategy applied in this thesis, "validity" is often divided into the three sub-groups of construct validity, internal validity and external validity (Riege, 2003; Yin, 2009). In the sections below, 3.4.1-3.4.4, each of the concepts of construct validity, internal validity, external validity and reliability are discussed in relation to the studies of the thesis.

3.4.1 Construct validity

According to Yin (2009, p. 40), construct validity concerns "identifying correct operational measures for the concepts being studied". This is related to the objectivity and neutrality of the research (Riege, 2003; Yin, 2009).

It can be hard to achieve construct validity in case study research, and data collection may be criticised for being subjective (Yin, 2009). However, Yin (2009, p. 41) states that in order to obtain construct validity in a case study, the researcher can apply the following three tactics: use multiple sources of evidence, establish a chain of evidence and have key informants review draft case study report.

All of the case studies of the thesis are based on multiple sources of data, where all of the cases include direct observations, complemented by one or more of the data sources of the following: interviews, internal company documentation and video recordings (see Table 3.2). In all of the papers that include video recordings as a source of data, the researchers behind the respective papers were the ones making the video recordings. In all of the case studies, representatives from the respective companies, familiar with the studied systems, have reviewed and approved drafts of the case study reports.

The case descriptions provided in the different case study-based papers in the thesis were made as detailed as possible, in order to establish a chain of evidence, so that the reader would be able to trace the results that were reached.

In paper III, the fact that the study was performed in an artificial setting, and not in actual assembly, raises issues regarding the construct validity of this study. To achieve high construct validity, the experiment was designed in collaboration with production engineers from the company. This way, the studied operations were meant to resemble those in an actual assembly situation as closely as possible.

3.4.2 Internal validity

Internal validity relates to causality and is therefore applicable mainly in relation to explanatory case studies (Riege, 2003; Yin, 2009). Internal validity can be difficult to achieve in case studies, as case studies investigate phenomena within often complex contexts, where causality can be difficult to establish (Yin, 2009). In order to achieve internal validity of case studies, Yin (2009) suggests the approaches of pattern matching, explanation building, addressing rival explanations and using logic models. Riege (2003) further suggests that internal validity can be helped by an approach where within-case analysis first is made, followed by cross-case analysis.

Identifying relations between the configuration of an in-plant materials supply system and performance is far from straightforward. In-plant materials supply systems are complex and tightly interrelated with the contexts in which they are operating. Hence, in order to enhance internal validity, all of the case studies of the thesis utilise pattern matching, meaning that empirically based patterns are compared with patterns predicted based on literature studies (Yin, 2009). Furthermore, in line with the suggestion of Riege (2003), papers II and VI include both within-case analyses and cross-case analyses. In papers I, II, V and VI, the possibility to establish causal relations is strengthened by the fact that these papers are based on case studies where comparisons are made between two situations: before and after some form of change to the system studied.

In the experiment of paper III, it was possible to change the configuration of the studied system in accordance with the aim of the paper. Accordingly, a high internal validity could be achieved.

3.4.3 External validity

The external validity of a case study is concerned with whether or not the results of the case study can be generalised and applied to other cases (Riege, 2003; Yin, 2009). A major criticism of the use of case studies, especially single case studies, is that the very limited sample is stated not to provide a basis for generalisation (Yin, 2009). However, as argued by Riege (2003) and Yin (2009), case study research relies on analytical generalisation, as opposed to statistical generalisation. External validity in case study research can be achieved using replication logic or by comparing the empirical data with the existing literature (Riege, 2003; Yin, 2009). The use of multiple case studies can result in generalisable conclusions, based on patterns that can be found between cases (Hill et al., 1999).

In all of the case studies of the thesis, the data and the results are compared to the existing literature, thereby enhancing the external validity of the studies. Most of the case study-based papers, the only exception being paper V, are based on multiple case studies, where similarities and differences can be found between the cases, thereby contributing to analytical generalisation.

The case studies of the thesis are based partly on quantitative data, but it should be noted that these data do not provide enough basis for statistical generalisation. In the papers, the quantitative data are used as input to the analyses, whereas the results are presented in more qualitative terms.

Related to the discussion of construct validity presented in Section 3.4.1, the external validity of the experiment of paper III can be questioned. As the study was performed in an artificial setting, it is not obvious that the results can be generalised to other settings, such as an actual assembly setting. However, as was stated in Section 3.4.1, the participation of production engineers from the company where the experiment was set contributed to making the experiment as realistic as possible.

3.4.4 Reliability

The reliability of a research study concerns the extent to which the results could be replicated (Bryman and Bell, 2011). To achieve reliability, the procedures used in a research study should therefore be carefully documented.

Case studies are often criticised for lacking replicability, as the results are considered to be tightly connected to the specific settings of the cases (Bryman and Bell, 2011). To overcome this, and to enable replication of results, careful documentation of the procedures and the data collected can be used. Accordingly, to enhance reliability, Yin (2009) suggests that case study protocols can be used and that case study databases can be developed.

The procedures for data collection used in the case studies in the thesis have been well documented, as have the actual data. A risk associated with the collection of data from video recordings, an approach used in several of the case studies as well as in the experiment, is that the performance of the operators may be affected by the fact that recordings are being made. It is difficult to eliminate this risk, but by explaining the purpose of the recordings, focusing on studies of the operations and not the respective operator, the researchers tried to increase the acceptance of the operators participating and making them feel relaxed.

In paper V, where a comparison is made between two situations (before and after a redesign of the in-plant materials supply system), some of the data for describing the situation before the transition were not collected until after the transition had taken place. The data collection performed before the redesign of the in-plant materials supply system had a broad scope and was not exclusively focused on the in-plant materials supply system, but was also used in a paper focusing on assembly performance (see Finnsgård et al., 2011). In fact, the level of detail with which the in-plant materials supply system was initially studied was not sufficient to fully support the analysis in paper V. Hence, the data regarding man-hour consumption in the in-plant materials supply system before the transition were not collected until after the transition had taken place, which meant that the researchers had to rely on secondary data from within the company, complemented and verified by interviews with the company staff. With an approach like this, there is a risk of reduced reliability, as data may have been lost or distorted over time. In order to support reliability, two types of data were used: both secondary data, in the shape of company documentation, and interview data from people within the case company.

In paper VI, two of the case studies (cases 6.2 and 6.3) included comparisons between an actual system and a system that was not in place and whose performance had therefore been predicted and calculated. The reliability of these comparisons would have been higher if it had been possible to use only data from actual systems, as there is a potential risk of the predictions and calculations being flawed. In order to enhance the reliability of case studies 6.2 and 6.3, several people from the case company were asked to give input to and to confirm the predictions and calculations being made.

Some of the studies included in the thesis can be considered as "action research". Action research was originally developed for application in social research and was meant to combine generation of theory with changing the studied system through the researcher acting on or in the system (Susman and Evered, 1978). According to Bryman and Bell (2011, p. 413), action research can broadly be defined as "an approach in which the action researcher and a client collaborate in the diagnosis of a problem and in the development of a solution based on the diagnosis". The author of the thesis has, in many of the studies, been part of the organisation where the research has been performed, in these cases Saab, and even of the project teams responsible for changing the in-plant materials supply systems being studied. In this context, it should be noted that the author's responsibility within Saab was not for performing the changes, but for studying and evaluating their respective outcome. Nevertheless, because of the author's involvement in these project teams, there could be a risk of the author being affected by the ideas and opinions within Saab and that the research thereby could be biased. This risk was, however, mitigated as the author, throughout the duration of his research, spent only approximately half of his time at Saab; the other half he spent at Chalmers University of Technology, where he interacted with fellow academic researchers and where he maintained regular contact with his research supervisors. Moreover, during the course of his research, the author also visited and performed studies at companies other than Saab. This further contributed to broadening the perspectives of the author and allowing him to have a more nuanced view of the systems and opinions at Saab.

4 Results

The current chapter presents the results of the thesis, responding to each of the research questions presented in Section 2.6. The results are based on the research papers included in the thesis. Figure 4.1 provides an overview of how the six papers included in the thesis are used to answer the three research questions. The remainder of the chapter is structured into three main sections (Sections 4.1-4.3), each of which addresses one of the research questions.

Research question 1 (RQ 1): How is assembly and in-plant materials supply performance affected by whether kitting or continuous supply is used?
(Addressed in Section 4.1)

Research question 2 (RQ 2): When kitting is used, how is in-plant materials supply performance affected by the location of the kit preparation?
(Addressed in Section 4.2)

Research question 3 (RQ 3): When continuous supply is used, how is man-hour consumption in in-plant materials supply affected by the size and type of the unit loads?
(Addressed in Section 4.3)

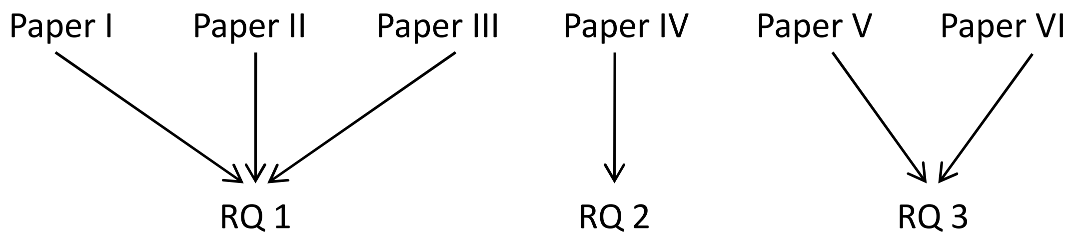


Figure 4.1 *Overview of how the six papers included in the thesis contribute to answering the three research questions*

4.1 How is assembly and in-plant materials supply performance affected by whether kitting or continuous supply is used?

This section presents the answer to research question 1, focusing on the performance impact that is related to whether kitting or continuous supply is used. Accordingly, as illustrated in Figure 4.1, the section is based on the studies included in papers I-III. The empirical studies comparing kitting and continuous supply have focused on the performance areas of man-hour consumption, product quality and assembly support, inventory levels and space requirements, and flexibility. Alongside the performance area of control and visibility, these are the performance areas most frequently mentioned in the existing literature on kitting and continuous supply, as presented in Section 2.3.

4.1.1 Man-hour consumption

In assembly, the use of kitting to present parts can reduce man-hour consumption compared to continuous supply. Within the literature, two different aspects of kitting have been stated to contribute to the reduced man-hour consumption: 1) often, kitting is associated with parts being presented closer to the assembly object than is feasible with continuous supply, which can then reduce or eliminate the time needed for walking (Johansson, 1991) and 2) with kitting, no time needs to be spent searching for parts (Ding and Puvitharan, 1990; Johansson, 1991; Hua and Johnson, 2010). By use of an experiment, paper III of the thesis shows that both of these aspects are significant in relation to the man-hour consumption in assembly. In the experiment of paper III, the elimination of time spent searching for parts had a significant impact on the overall time spent fetching parts, even when the number of part variants was small. In the two cases of paper I, the use of kitting, compared to the use of continuous supply, reduced man-hour consumption in assembly mainly by improved parts presentation, due to the fact that with kitting, not all part numbers need to be presented at once, as they do with continuous supply. It should be noted that the space consumption of parts supplied by continuous supply, and thereby the time spent walking to fetch these parts, is closely related to the size and type of unit loads used, as was illustrated in the case studies of papers V and VI of the thesis.

As acknowledged in the previous literature (Baudin, 2002; Hua and Johnson, 2010; Caputo and Pelagagge, 2011), kitting is often combined with continuous supply, so that some parts are supplied by kitting and others by continuous supply. Recognising this fact, paper II studies the impact that the proportion of parts supplied by kitting has on the man-hour consumption of the assemblers. Even though the fetching times, in the cases studied in the paper, were considerably shorter for parts presented in kits compared to parts presented in component racks, there was no direct relation between the average time for fetching each part and the proportion of parts presented in kits instead of in component racks. Instead, the average fetching time per part differed substantially between the four cases studied in the paper, with no direct relation to the proportion of parts kitted. This was found to be related to the number of parts that the assembler fetched on each visit to the component racks. Since an assembler often fetched more than one part per visit to the component racks, it was not certain that kitting one additional part would reduce the number of visits to the component racks by one. The number of parts fetched per visit to the component racks is related to the characteristics of the parts (e.g. the part size) and to how the assembly operations are performed (e.g. in terms of the order in which different parts are assembled: parts that are assembled together are likely to be fetched together, if this is feasible).

Compared to continuous supply, performing kit preparation in a materials flow is associated with additional handling and, assuming that the kit preparation is performed manually, with additional man-hour consumption. With continuous supply, parts are often presented at the assembly stations in the original packaging sent from the supplier, whereas with kitting, parts generally need to be repacked from their original packaging to kits. When kitting is performed in a separate location, as in the two cases studied in paper I, an additional transportation of the parts is also needed. Furthermore, since kits often seem to contain fewer parts than part number-specific unit loads, the frequency with which the kits need to be supplied can be high. In the cases studied in paper I, the increased man-hour consumption in the in-plant materials supply, resulting from the introduction of kitting, more than outweighed the reduced man-hour consumption in assembly, resulting in an overall increase of the man-hour consumption in the assembly plant. All in all, the results of paper I clearly show that the additional materials handling associated with kitting, compared to continuous supply, can be considerable. However, it should be noted that in case there is a need for very space-efficient parts presentation, the use of continuous supply may be associated with a need for repacking into smaller unit loads. As was illustrated in papers V and VI, this repacking can require considerable man-hour consumption.

4.1.2 Product quality and assembly support

In both cases studied in paper I (cases 1.1 and 1.2), parts presentation in kits seems to have had both positive and negative effects on the support provided to the assemblers, compared to when parts were presented in component racks supplied by continuous supply. In both cases, the assemblers found that the assembly work was facilitated by kitting, since there was less need for identifying which parts should be assembled and less risk of confusing parts. Hence, the simplified parts presentation of kitting, associated with presenting only the parts needed for each assembly object, can clearly support assembly. In case 1.2, some difficulties had, however, been registered related to how the parts were presented within the kits. Since no formal structure existed in the kits, searching for parts was sometimes necessary and some parts could be confused. Conversely, in case 1.1, where the support to the assembly had been an explicitly stated motive for introducing kitting, the rigid structure of the kits was appreciated by the assemblers. Accordingly, it seems that a structured kit can offer better support to the assemblers than a kit without formal structure.

In both case companies from cases 1.1 and 1.2, kits containing the wrong parts had sometimes been delivered to the assembly stations, something that could of course have a negative impact on product quality. Even though most of these mistakes were discovered and corrected at the assembly stations, and thus did not impact on final product quality, resources were required for correcting the mistakes. Compared to when parts are picked from component racks directly at an assembly station, more resources are required for correcting a mistake where the wrong part has been picked at a kit preparation area, some distance from the assembly stations. Hence, in order for the kits to provide a reliable support that can increase assembly quality, the quality of the kits needs to be ensured.

4.1.3 Inventory levels and space requirements

As stated in Section 2.3.3, based on the previous literature (Sellers and Nof, 1986; Hua and Johnson, 2010), kitting can, compared to continuous supply, result in inventory levels and space requirements being reduced at the receiving assembly stations, but increased upstream of assembly, because of the kit preparation. This was confirmed by the case studies of paper I (cases 1.1 and 1.2), where the introduction of kitting meant that component racks, and thereby inventory, were moved from the assembly stations to a kit preparation area that was set up. In both cases, overall inventory levels increased as a result, as the introduction of kitting in both cases was associated with a new process step being added. It can be noted that neither of the two companies stated that the reduction of inventory levels, other than at the assembly stations, was a motive for introducing kitting. Potentially, this can have affected the configuration of the materials supply by kitting. For example, as stated in the literature (Johansson, 1991; Hua and Johnson, 2010) and as was pointed out in Section 2.3.3, for parts numbers that are used at multiple locations, continuous supply is associated with multiple storage locations (one at each point of use), whereas with kitting, it is possible to store each part number in only one location in the kit preparation area. However, as noted in case 1.2, where some part numbers were in fact used at multiple locations, the company had not taken advantage of the possibility to reduce the number of storage locations, but had instead chosen to focus on keeping man-hour consumption low in the kit preparation.

4.1.4 Flexibility

As was stated in Section 2.3.4, kitting has been stated to be associated with a higher level of flexibility than continuous supply (Sellers and Nof, 1986; Bozer and McGinnis, 1992). The results of the thesis provide support for this notion.

Because of the space-efficient parts presentation that kitting enables, illustrated in several of the case studies of the thesis, it seems clear that kitting, compared to continuous supply, can increase the flexibility for handling a large number of part variants or variations in production volume. As described by Wänström and Medbo (2009), with continuous supply, this flexibility can be restricted by space limitations for presenting parts at the assembly stations, making it difficult to display a large number of part variants. Even though the use of small unit loads in continuous supply can reduce the space requirements at the assembly stations, as illustrated in papers V and VI, kitting has an even greater potential in this respect. With kitting, the space available at the assembly stations is not a restriction on how many part numbers can be handled at the assembly stations.

The results of paper I show that kitting, compared to continuous supply, can be associated with a greater flexibility for rebalancing an assembly line. In case 1.1, kitting increased the flexibility for rebalancing the assembly line, as it was possible to move assembly tasks between assembly stations without rearranging any component racks. This is found to be a general advantage associated with kitting, compared to continuous supply: since fewer component racks and parts are located at the assembly line when kitting is used, less rearranging is necessary when a rebalancing of the assembly line is taking place. However, in case 1.1, the use of two different kits for different sections of the assembly line, together with the use of kit containers with specific, fixed positions for each part, constituted a restriction on the flexibility. The reason was that the different structures of the two kits made it difficult to move parts between the two kits, which in turn made it difficult to move assembly operations between the two sections of the assembly line that were supported by different kits. It seems that the more different kits that are used, the more will the flexibility be restricted, especially if kit containers are used that have specific, fixed positions for each part. In fact, if station-specific kits were to be used, like in case 1.2, and were to be designed with a specific, fixed position for each part, like in case 1.1, it would not be possible to move assembly operations between different assembly stations without first redesigning the kits and the kit containers.

4.2 When kitting is used, how is in-plant materials supply performance affected by the location of the kit preparation?

The current section presents the answer to research question 2, dealing with in-plant materials supply by kitting and the impact that the location of the kit preparation can have on in-plant materials supply performance. As illustrated in Figure 4.1, the research question is answered based on the studies presented in paper IV.

Based on a literature review, paper IV identified seven performance areas that were likely to be affected by which location is used for the kit preparation: 1) the amount of transportation required, 2) the inventory levels and space requirements, 3) the potential for visual control of the kit preparation and of the delivery of kits, 4) the flexibility in relation to the demands of the assembly, 5) the efficiency of the kit preparation, 6) the quality of the kits and the responsiveness to quality deficiencies and 7) the ability to achieve continuous improvement. Furthermore, the literature review provided a preliminary understanding of *how* these performance areas can be affected by which location is used. The potential links, identified in the literature, between the location of the kit preparation and each of the seven performance areas are presented in Table 4.1.

Table 4.1 *Potential relations between performance and the location of the kit preparation*

Performance area	Potential relation between performance and the location of the kit preparation
Amount of transportation	Increased amount of transportation by long transport distances and frequent transports
Inventory levels and space requirements	Overall inventory levels and space requirements decreased by a high degree of centralisation
Potential for visual control	Visual control possible if distance between assembly and kit preparation is short
Flexibility	Improved flexibility by increased space available for kit preparation
Efficiency of the kit preparation	Improved efficiency if free space without restrictions is available for kit preparation Risk of reduced utilisation of pickers with decentralised kit preparation areas far apart
Quality	Increased quality if assemblers perform kit preparation Improved responsiveness to quality problems if kit preparation is close to assembly
Ability to achieve continuous improvement	Improved ability if assemblers perform kit preparation

Based on the relations identified in the literature review, paper IV used three case studies (cases 4.1-4.3) to further study how the location of kit preparation affects in-plant materials supply performance. The findings from these case studies are presented in Sections 4.2.1-4.2.7, where each section corresponds to one of the seven performance areas identified in the literature.

4.2.1 Amount of transportation

Based on the three case studies of paper IV, it seems that kit containers often contain fewer parts than do part number-specific unit loads. Accordingly, the frequency of kits leaving a kit preparation area is then higher than the frequency with which unit loads enter the kit preparation area. This then indicates that the amount of transportation could be lower the closer the kit preparation area is to the assembly stations. However, as was also found in paper IV, a further aspect that should be considered is that having a separate kit preparation area between storage and assembly stations results in an extra transportation of each part, compared to when the kit preparation is performed either in the storage area or in direct association with the assembly stations.

4.2.2 Inventory levels and space requirements

In all three cases studied in paper IV (cases 4.1-4.3), it seems that the location of the kit preparation did not have any significant impact on the overall inventory levels within the plants. In the cases, overall inventory levels were based mainly on other aspects than in-plant materials handling and storage cost. However, it seems that the space requirements for preparing the kits can differ depending on where the kits are prepared. In case 4.3 of paper IV, where kits were prepared in storage, no more space was consumed than had the parts been supplied to the assembly stations without first being kitted, i.e. had they been supplied by continuous supply instead of kitting. In cases 4.1 and 4.2, instead, the kit preparation required an area in addition to the area in the main storage.

4.2.3 Potential for visual control

In paper IV, it was found that the distance between the kit preparation and the receiving assembly station affects the potential for visual control over the inventory levels. In cases 4.1 and 4.2, where kit preparation was performed close to the assembly stations, visual control was used to regulate the pace of the kit preparation in relation to the pace of the assembly operations. In case 4.3, where the distance was much longer and made visual control impossible, it often occurred that kits were delivered to the assembly stations before they were due, which then resulted in problems with overfull buffers.

4.2.4 Flexibility

The flexibility in terms of variations in production volumes and product mix was in cases 4.1-4.3 found related to the space available for expanding the kit preparation area. In case 4.2, where the kit preparation area was located in direct association with the two assembly stations it was supplying, the possibilities to expand the kit preparation area were limited, as the size of the area was strongly linked to the size of the assembly stations. In cases 4.1 and 4.3, instead, where the kit preparation was performed in a separate kit preparation area and in storage, respectively, there was a higher flexibility for expanding the area used for kit preparation and, thereby, for handling variations in production volumes and product mix.

4.2.5 Efficiency of the kit preparation

In terms of efficiency of the kit preparation, one general difference could be discerned related to the location of the kit preparation. This difference was based on the level of freedom to design the kit preparation area. In case 4.1, where the kit preparation was performed in a separate area, not linked to either storage or assembly stations, there was a relatively large freedom to design the kit preparation area. In cases 4.2 and 4.3, where the assembly stations and the storage layout, respectively, had to be considered, the freedom to design the kit preparation area was more restricted. In case 4.2, the layout of the kit preparation area had been adapted in accordance with the assembly line, along which the kit preparation area was located. Because of the assembly line, it was only possible to supply one side of the kit preparation with parts from the outside. In case 4.3, the distance between the two sections in the storage (one section for pallet storage and one section for storage of smaller containers) resulted in considerable travel distances during the kit preparation.

For decentralised kit preparation areas, there can be difficulties achieving and maintaining a high level of utilisation of the operators in the kit preparation area when production volumes change. In case 4.1, where kit preparation was performed in a decentralised location, between storage and assembly stations, there were difficulties achieving a high level of utilisation of the operators, whereas in case 4.3, where kit preparation was performed in a central storage, it was easier to balance the workload between different operators. However, in case 4.2, where kit preparation was performed in direct association with the assembly stations, the potential difficulties were counteracted as subassembly tasks, which were possible to perform off-line, were transferred back and forth between the assembly stations and the kit preparation area when production volumes changed, thereby increasing flexibility.

4.2.6 Quality

The quality of the kits is related to a large number of aspects and is difficult to link directly to the location of the kit preparation. A difference can, however, be seen in relation to the ability to respond to quality deficiencies and replace faulty parts. In cases 4.1 and 4.2, where the kit preparation was performed close to the assembly stations, the replacing of a part was much quicker than in case 4.3, where the kit preparation was performed in a storage area further away from the assembly stations.

4.2.7 Ability to achieve continuous improvement

The findings from cases 4.1-4.3 support the notion that continuous improvements are easier to achieve when the same operators are responsible for both assembly and kit preparation. Based on the cases, it seems that continuous improvement work can be facilitated both by the fact that the operators then have an understanding of both assembly and kit preparation, and by having potential changes and reorganisations taking place within the same organisational unit of the company. In case 1, the company had observed both of these effects, as kit preparation had first been performed by the assemblers themselves and later by other operators within the same organisational unit as the assemblers.

4.3 When continuous supply is used, how is man-hour consumption in in-plant materials supply affected by the size and type of the unit loads?

Responding to research question 3, this section focuses on in-plant materials supply and the impact that the size and type of unit loads have on the man-hour consumption of in-plant materials supply. The evidence presented in the section is based on the studies of papers V and VI, as illustrated in Figure 4.1.

Naturally, the size of the unit loads used for delivering parts within the in-plant materials supply affects the required frequency with which unit loads need to be delivered. In case 6.1 (presented in paper VI), a reduction of unit load size (associated with a transition to minomi) resulted in a heavy increase in the delivery frequency, which, in turn, increased the man-hour consumption in the in-plant materials supply. However, as shown in paper V, based on case study 5.1, it is clear that the man-hour consumption of an in-plant materials supply system is not linked only to the size of the unit loads. There are fundamental differences between how large pallets, compared to smaller unit loads, are delivered within an assembly plant, meaning that the increased delivery frequency required for smaller unit loads does not necessarily result in an increased man-hour consumption. In case 5.1, where, for a large proportion of the parts, the size of the unit loads was reduced considerably, it was possible to maintain the number of operators performing the in-plant deliveries by expanding the use of in-plant milk-run deliveries, on the expense of forklift deliveries. Accordingly, the unit load size can have both a direct effect on the man-hour consumption in the in-plant materials supply, changing the delivery frequency, and an indirect effect, by influencing the in-plant materials supply configuration. This is illustrated in Figure 4.2.

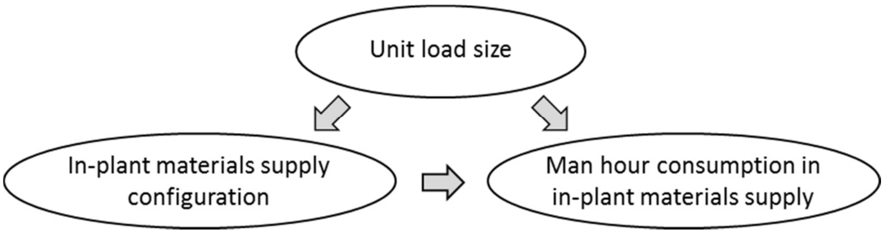


Figure 4.2 *Representation of how the unit load size can affect man-hour consumption in in-plant materials supply*

As found both in paper V and in paper VI, the use of small unit loads can enable parts presentation on flow racks at the receiving assembly stations, which, in some cases, can reduce the number of process steps within the materials supply operations. This occurs when the use of large unit loads, that are not feasible to place and handle on flow racks, would require a separate inventory buffer being placed between the point of delivery, be it a storage or a sub-assembly process, and the receiving assembly station.

In order to reduce the unit load size, it may be necessary to perform repacking within the assembly plant, which was seen both in case 5.1 and in case 6.1. In case 5.1, the company wanted to continue transporting parts in EUR-pallets from suppliers, partly because of contractual agreements with the suppliers and partly because of the high fill-rate in truck transport that was possible when EUR-pallets were used. This meant that repacking was required within the assembly plant, after the parts had been received from the suppliers. As seen both in case 5.1 and in case 6.1, repacking can be very man-hour consuming, thereby significantly increasing man-hour consumption in the in-plant materials supply. Accordingly, as seen in cases 6.2 and 6.3, it can be advantageous if it is possible to use the smaller unit loads in the whole materials flow, so that no repacking is required.

5. Discussion and future research

In the current chapter, a discussion of the thesis and its contributions is presented. First, in Section 5.1, the results of the thesis are discussed in relation to each of the three research questions. Thereafter, Section 5.2 discusses the findings of the thesis in relation to the thesis aim. Section 5.3 provides a discussion of the contribution of the thesis. In Section 5.4, a discussion is presented regarding the potential for generalising the findings of the thesis. Finally, Section 5.5 brings up areas that are in need of further research.

5.1 Discussion of results

The current section discusses the results of the thesis, presented in Chapter 4, and their implications in relation both to industry and to theory. In Sections 5.1.1-5.1.3, each of the three research questions of the thesis is discussed separately. Thereafter, Section 5.1.4 presents a discussion of the possibilities of combining kitting and continuous supply, so that some parts are supplied by kitting and others by continuous supply, which is a common approach within industry. Finally, Section 5.1.5 presents a summary of the relations between materials feeding principles and performance, considering the configuration and the context of the in-plant materials supply system.

5.1.1 Discussion of the answer to research question 1

This section discusses the results presented in Section 4.1, answering research question 1: "How is assembly and in-plant materials supply performance affected by whether kitting or continuous supply is used?"

Man-hour consumption

The existing literature provides little information regarding the overall man-hour consumption associated with kitting and continuous supply. Several publications (Ding and Puvitharan, 1990; Johansson, 1991; Hua and Johnson, 2010; Caputo and Pelagagge, 2011) agree that man-hour consumption in assembly can be reduced by kitting, but when it comes to the man-hour consumption in materials supply, there exist conflicting reports, as noted by Hua and Johnson (2010) and discussed in Section 2.3.1 of the thesis. Based on the results of the thesis, presented in Section 4.1, it seems that kitting, compared to continuous supply, is generally associated with more man-hour consumption in the in-plant materials supply. Furthermore, it seems that the additional materials handling associated with the preparation and delivery of kits is likely to exceed the savings in man-hours that kitting can enable in assembly. When studying the man-hour consumption for fetching parts at the assembly stations, the average savings per part presented in kits, as opposed to in component racks, were relatively small in most of the studies: around 1-2 seconds. In manual kit preparation, it is difficult to achieve an average picking time per part that is as low as this. Moreover, in addition to the kit preparation itself, the transportation between kit preparation area and assembly can add further to the required man-hour consumption.

For kitting to result in overall less man-hour consumption than continuous supply, it is necessary either that the additional man-hour consumption in the materials supply is small, or that the savings at the assembly stations are great, or preferably both. First of all, if there is need for very space-efficient parts presentation at the assembly stations, materials supply by continuous supply may require repacking from larger into smaller unit loads. As noted in papers V and VI, repacking like this is man-hour consuming and, accordingly, a materials flow based on continuous supply where repacking is performed may not require any less man-hour consumption than an equivalent materials flow based on kitting. Moreover, in some cases, the improvements in parts presentation at the assembly station may be large enough to compensate for the additional materials handling associated with the kit preparation. As discussed by Deechongkit and Srinon (2009), when a very large amount of part numbers need to be presented at each assembly station, the walking distances of the assemblers may be very long in case continuous supply is used. In cases like these, the savings in man-hour consumption associated with kitting can be considerable. There can also be other cases where continuous supply results in considerably more man-hour consumption for fetching parts than kitting. This could include cases where it is difficult for the assembler to get to the component racks to fetch parts, for example, in automobile assembly, when assembly is performed inside the automobile, making it necessary for the assembler to step in and out of the automobile to be able to fetch parts from the component rack. In a case like this, parts presentation in a kit, which can be presented inside the automobile, can offer considerable time savings for the assembler.

As has been stated in the thesis, the man-hour consumption is closely related to running cost in production. However, it should be recognised that the cost of man-hours may vary between different organisational units within a company. Moreover, in some assembly plants, more than one company is operating, in which case the cost of man-hours may vary between the different companies. For example, a company may have been hired to perform some assembly or materials handling tasks. It is not uncommon that the cost of man-hours in materials handling is lower than the cost of man-hours in assembly. Under circumstances like these, assuming the kit preparation is performed by staff from the materials handling division, these differences need to be considered when a choice between kitting and continuous supply is made, as the lower cost of man-hours in materials handling may offset the additional man-hour consumption in materials handling that is often associated with kitting, compared to continuous supply. Accordingly, not only the overall man-hour consumption should be considered, but the man-hour consumption in materials handling should be separated from that in assembly. As the wage distribution is often linked to the country where the assembly plant is located, this is important to consider not least for companies that operate assembly plants in several countries.

Product quality and assembly support

One of the areas where kitting is often stated to offer benefits is the area of product quality, as the use of kits to present parts at the assembly stations is supposed to provide support to the assembler, making it easier to achieve a high product quality (Sellers and Nof, 1986; Johansson, 1991; Bozer and McGinnis, 1992; Caputo and Pelagagge, 2011). In the case studies of paper I, it was clear that the assemblers appreciated the support provided by the kits, as the simplified parts presentation enabled them to focus on their assembly tasks, without having to think about which parts to pick. However, since there is a risk that mistakes are made in the kit preparation, resulting in the kits containing the wrong parts, it is not obvious that product quality will actually be higher with kitting than with continuous supply. In order to utilise the potential quality-related benefits of kitting, it is necessary that the kit preparation is performed without mistakes. The use of picking support in the shape of, for example, pick-to-voice or pick-to-light systems, can be useful in this context, as can training of the operators in the kit preparation area. Furthermore, as suggested in the previous literature (Brynzér and Johansson, 1995; Baudin, 2002), picking accuracy is likely to be higher when assemblers, who are familiar with the assembly operations, are responsible for the kit preparation.

The assembly support that parts presentation in kits can enable is likely to be more valuable in some contexts than in others. For example, when assembly cycles are longer, each assembly cycle contains a larger amount of work content, which could increase the need for support. In relation to long cycle assembly, Engström et al. (1993) discuss parts presentation in kits and argue that parts should be presented according to the product structure, in order to support assembly. Moreover, a high staff turnover rate and a high proportion of inexperienced assemblers are likely to be factors that increase the need for support of the assemblers. In contexts like these, assuming the quality of the kit preparation can be ensured, kitting is likely to be more valuable than in contexts where the staff turnover rate is low and where the assemblers are experienced. It should be noted that staff turnover rate may differ between companies, between industries and between geographical regions. Therefore, when making a choice between kitting and continuous supply, there is a need for considering local conditions in terms of staff turnover rate, as well as level of experience among the assemblers.

Flexibility

Supporting statements in the existing literature (Sellers and Nof, 1986; Bozer and McGinnis, 1992), the thesis has found that flexibility, both in terms of production volumes and product mix, can be improved by the use of kitting, compared to continuous supply. The importance that these types of flexibility can have is related to the context. Accordingly, volume flexibility is especially important in contexts where production volumes vary, for example because of demand fluctuations. Similarly, mix flexibility is especially important in contexts where there is a demand for a large variety of products, which is likely to be associated with a large amount of part variants.

As presented in Section 2.3.4 (see Swaminathan and Nitsch, 2007), kitting can reduce the flexibility to change the sequence of the assembly objects, as the kit preparation requires that information of this sequence is available in advance. It seems that this flexibility can be affected by where the kit preparation is performed: if the kit preparation is performed far away from the assembly stations, the information regarding the sequence of the assembly objects is likely to be required further in advance than if the kit preparation is performed in direct association with the receiving assembly station.

There appears to be a potential conflict between the flexibility and the assembly support in relation to whether or not the kit should be structured. Based on cases 1.1 and 1.2, it seems that structured kits can offer better assembly support, but on the other hand, the structure of the kits can make it difficult to move parts between different assembly stations, for example in association with a rebalancing of the assembly line. This highlights the need for a company to carefully consider which performance areas should be prioritised before deciding which materials feeding principle to use.

Inventory levels and space requirements

Paper I studied the effects of using kitting and continuous supply in two different cases (cases 1.1 and 1.2). In both cases, kitting resulted in space being made available at the assembly line, but this space was found fully useful only in case 1.2, where there was not enough space available to present all parts required at the assembly line. In case 1.1, where the proportion of parts supplied by kitting was larger than in case 1.2, large amounts of space were made available at the assembly line, but the company did not know how this space should be utilised, because of the position and somewhat limited accessibility of the assembly line. Hence, when evaluating the effects associated with kitting and continuous supply, respectively, not only the amount of available space is important, but also the location and potential use of this space.

The thesis has further shown that the use of kitting is not necessarily associated with lower levels of inventory than continuous supply, as is sometimes assumed in the literature (see Caputo and Pelagagge, 2011). Both in case 1.1 and in case 1.2, the inventory levels instead increased slightly when kitting was introduced.

5.1.2 Discussion of the answer to research question 2

This section discusses the results presented in Section 4.2, answering research question 2: "When kitting is used, how is in-plant materials supply performance affected by the location of the kit preparation?"

From the results of the thesis, presented in Section 4.2, it seems that within several performance areas, performance benefits from having the kit preparation located close to the receiving assembly stations. However, there are also drawbacks associated with having the kit preparation area in direct association with the assembly stations. One important example concerns the flexibility to handle variations in production volumes and product mix. This flexibility is closely related to the space available within the kit preparation area and when the kit preparation area is located in direct association with the assembly stations, this space can be restricted. Accordingly, having the kit preparation area in direct association with the assembly stations can eliminate or restrict one of the main benefits of kitting, compared to continuous supply.

It should be noted that space to prepare kits can be limited also in locations other than at the assembly stations. The space availability at different potential locations for kit preparation depends on a number of aspects, such as plant layout, and accordingly differs between different plants.

One of the general drawbacks of kitting, compared to continuous supply, is the space requirements in the materials flows, associated with the kit preparation (Bozer and McGinnis, 1992; Hua and Johnson, 2010). However, if the kit preparation is performed in storage, no separate area has to be occupied for this activity, which means that this option can be suitable to apply in contexts where space is limited within the assembly plant. By organising in-plant materials supply by kitting like this, space efficiency can be achieved both at the assembly stations and in the materials flows. However, for kit preparation to be performed in storage, the configuration of the storage needs to accommodate this, for example in terms of aisle width and picking height, so that the pickers have easy access to all part numbers. If this is not the case, the man-hour consumption in the kit preparation may be increased.

5.1.3 Discussion of the answer to research question 3

This section discusses the results presented in Section 4.3, answering research question 3: "When continuous supply is used, how is man-hour consumption in in-plant materials supply affected by the size and type of the unit loads?"

In case space-efficient parts presentation is required, small unit loads need to be used in order for continuous supply to constitute a competitive alternative to kitting. As stated before in the thesis, using smaller unit loads to present parts can improve both time efficiency and flexibility in assembly (Wänström and Medbo, 2009).

Based on the results presented in Section 4.3, it is clear that the man-hour consumption of the in-plant deliveries by continuous supply does not need to increase by the use of small unit loads. Even though delivery frequency may increase considerably, it seems there is a potential for efficient in-plant materials supply when small unit loads are supplied by continuous supply. Accordingly, the potential benefits that continuous supply holds over kitting, in terms of lower man-hour consumption in the in-plant materials supply, can, at least in some cases, be applicable regardless of whether small or large unit loads are used.

A prerequisite for man-hour consumption to be kept low when continuous supply is used is that repacking to smaller unit loads can be avoided. Hence, when choosing between kitting and continuous supply, it should be considered whether or not continuous supply can be used without repacking. If there is not enough space at the assembly stations to present parts by continuous supply without first performing repacking to smaller unit loads, the man-hour consumption associated with these operations can offset the advantage of not having to prepare kits. As illustrated in papers V and VI, repacking can be avoided if it is possible to arrange the parts in suitable unit loads already at the supplying process, regardless of whether it is located in-house or at a supplier plant.

5.1.4 Combinations of kitting and continuous supply

As stated before in the thesis, the options available in the choice between kitting and continuous supply include various combinations of the two materials feeding principles, where some parts are supplied by kitting and others by continuous supply. A combination of kitting and continuous supply has the potential to combine some of the benefits of both principles, and can thus constitute a viable alternative to using only a single materials feeding principle. However, not all potential benefits are likely to be realised when the two materials feeding principles are combined. The current section presents a discussion of combinations of kitting and continuous supply.

One reason for combining kitting with continuous supply is to achieve the space savings at the assembly stations, associated with kitting, while at the same time not having to spend more man-hours than necessary repacking parts into kits. A potential approach for achieving this is to kit mainly those parts for which several variants exist, while supplying the rest by continuous supply. The parts with many variants are generally those that occupy the most space at the assembly stations if continuous supply is used. Accordingly, kitting those parts for which several variants exist offers relatively space-efficient parts presentation, thereby facilitating parts presentation and increasing flexibility. Furthermore, the assemblers in cases 1.1 and 1.2 of paper I stated that the kits supported their work mainly by reducing the need for identifying which parts should be assembled. Accordingly, from this perspective too, kitting those parts for which several variants exist seems appropriate. In contrast, kitting the parts that are included in all assembly objects, and for which no variants exist, seems to offer the least potential for reducing space requirements at the assembly stations, as well as for supporting the assemblers in terms of choosing the right parts to assemble.

Another criterion for deciding which parts to supply by kitting and which to supply by continuous supply could be the size of the parts. For the assemblers, it may be easier to remember how the large parts should be assembled, as they are likely to constitute more central elements of the product being assembled, whereas more support may be needed for the smaller parts. This could then be a reason for presenting small parts in kits, where it can be easier to structure the parts presentation to support the assembly. Furthermore, small parts are generally easier to handle than larger parts and the kit preparation may therefore be more efficient if the parts included in the kits are small.

Caputo and Pelagagge (2011) suggest that when kitting and continuous supply are combined, the value of the different parts could be a criterion when deciding which parts should be supplied by which principle. Based on a notion that kitting is associated with lower inventory levels than continuous supply, Caputo and Pelagagge (2011) suggest that the part numbers with the highest value per part are the most suitable candidates for kitting. However, based on the results of the thesis, it is clear that overall inventory levels are not necessarily lower when kitting is used.

If applying a combination of kitting and continuous supply, where some parts are supplied by kitting and others by continuous supply, it is important to consider the results of paper II. If the potential man-hour savings in assembly, associated with kitting, are to be realised, the assembly operations need to be considered when the choice is made for which parts to supply by which principle. Two parts that are assembled right after another and can be fetched together should be presented close to each other at the assembly station in order to reduce the need for walking. Accordingly, even if there exist variants only for one of these two parts, it may still be beneficial to include both in the kit.

Some potential benefits of kitting are likely to be reduced when not all parts are supplied in kits. Naturally, the space requirements at the assembly stations are even smaller if all parts are supplied by kitting. Moreover, when presenting all parts for one assembly object in a kit, the assembler needs to spend a minimum of time thinking of what parts to pick and to assemble. When instead splitting the parts presentation between kitting and continuous supply, the risk of forgetting a part is greater. Furthermore, for a kit that contains all parts for an assembly object, it is possible to structure the parts in a manner that supports the assembly operations (Engström et al., 1993). This is more difficult if some parts are presented outside the kit, potentially in a component rack some distance away from the assembly object.

5.1.5 Summarising overview of the relations between kitting and continuous supply and performance

As has been established in the thesis, performance is related not only to which materials feeding principle is used, but also to configuration and to the context of the in-plant materials supply system. These relations were described in Chapter 2 and are illustrated again in Figure 5.1. Further specifying the relations in Figure 5.1, Table 5.1 presents a summary of information from the theory presented in Chapter 2, the results presented in Chapter 4 and the discussion in Section 5.1. In Table 5.1, information from the theory is presented in white, information from the results is presented in light grey and information from the discussion is presented in dark grey. Much of the information highlighted in light grey, i.e. as being results of the thesis, constitutes confirmations of relations that have been suggested in the literature.

The information in Table 5.1 should be read from left to right. In the column "Performance-related effects associated with kitting and continuous supply", a summary is presented of which effects can be associated with each of the two materials feeding principles. For each of the effects listed in this column, it is possible to get an overview also of how that effect is related to the context of the in-plant materials supply system and to the configuration of the in-plant materials supply system, by viewing the information presented in the two rightmost columns of Table 5.1. A further description of how the information presented in Table 5.1 can be utilised to support a choice between kitting and continuous supply is presented in Section 5.2.

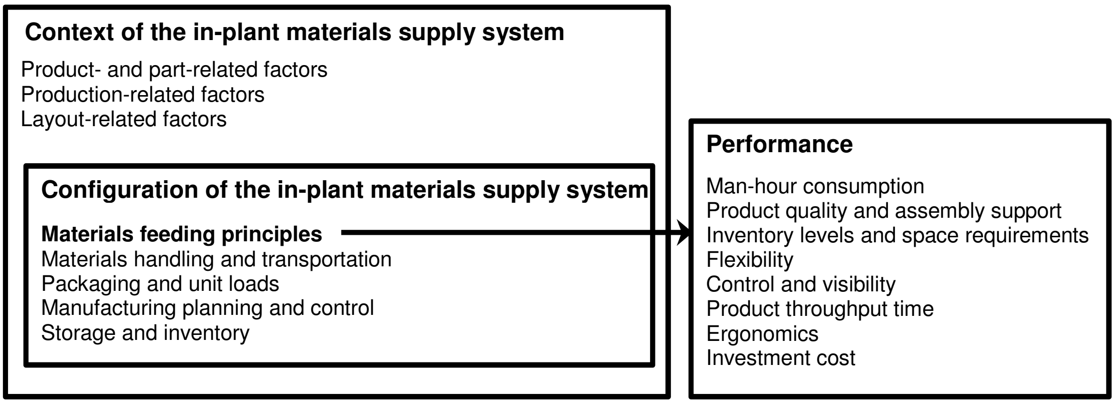


Figure 5.1 *Overview of the relations between materials feeding principles and performance, considering the configuration and the context of the in-plant materials supply system*

Table 5.1 *Detailed summary of the relations between materials feeding principles and performance, considering the configuration and the context of the in-plant materials supply system. Information presented in light grey is derived from the results of the thesis, information presented in white is derived from theory, while information presented in dark grey is derived from the discussion presented in Section 5.1.*

	Performance-related effects associated with kitting and continuous supply	Relation to the context of the in-plant materials supply system	Relation to the configuration of the in-plant materials supply system as a whole
Man-hour consumption	- Man-hour consumption in assembly can be reduced by kitting as space-efficient parts presentation can enable short walking distances	- If it is difficult to reach the component racks, e.g. when parts are assembled inside an automobile, parts presentation in a kit, close to the assembly object, is especially advantageous	- The advantages of kitting are especially apparent if continuous supply cannot be performed by use of small unit loads - Parts that are assembled together should be presented together (i.e. using the same materials feeding principle)
	- Man-hour consumption in assembly can be reduced by kitting because of reduced time searching for parts	- Searching for parts is especially time consuming when there is a large amount of part numbers at each assembly station	
	- Man-hour consumption in materials supply can be increased by kitting because of additional handling associated with preparation and transportation of kits	- Parts that are large and heavy may require longer time to handle and can therefore be unsuitable to repack, e.g. into kits	- The number of parts per kit container compared to the number of parts per part number-specific container determines the relative delivery frequency of the two principles - When continuous supply cannot be achieved without repacking, the additional handling associated with kitting can be offset
Product quality and assembly support	- Can be improved by kitting because of less risk of confusing parts at the assembly stations	- Assembly support can be especially important if assembly cycles are long or if there are many part variants - Assembly support can be especially important if staff turnover rates are high and if many assemblers are inexperienced	- Process support such as pick-to-light or pick-to-voice can be useful to ensure quality in the kit preparation
	-Can be worsened by kitting if quality is not ensured in the kit preparation		- Process support such as pick-to-light or pick-to-voice can be useful to ensure quality in the kit preparation
	- Can be worsened by kitting as the additional handling increases the risk of damage to parts	- The risk of damage is related to the sensitivity of the parts	- When continuous supply cannot be achieved without repacking, the additional handling associated with kitting can be offset
Inventory levels and space requirements	- Can be reduced at the assembly stations when kitting is used, as inventory is moved upstream, compared to continuous supply	- Low space requirements are especially important when there are many part variants and when assembly cycles are long. - The available space both at the assembly stations and upstream should be considered	- Kit preparation should not be performed at the assembly stations if space is limited there - The advantages of kitting are especially apparent if continuous supply cannot be performed by use of small unit loads
	- Can be increased upstream of assembly when kitting is used, as inventory is moved here, compared to continuous supply	- The available space both at the assembly stations and upstream should be considered	- If kit preparation is performed in storage, inventory levels may not increase, compared to continuous supply

Flexibility	- Volume and mix flexibility can be improved by kitting because of the space-efficient parts presentation	- Volume flexibility is especially important in case of demand fluctuations; mix flexibility is especially important if there is demand for a large variety of products	- The potential flexibility associated with kitting may be lost if kit preparation is performed in a very restricted area, e.g. directly by the assembly stations - The advantages of kitting are especially apparent if continuous supply cannot be performed by use of small unit loads
	- Volume flexibility can be improved by kitting as fewer component racks need to be moved in case of an assembly line rebalancing	- Volume flexibility is especially important in case of demand fluctuations	
	- Flexibility to change the sequence of the assembly objects can be reduced by kitting, as the kit preparation requires information of this sequence in advance		- If kit preparation is performed far away from the assembly stations, information of the sequence of the assembly objects is likely to be required further in advance
Control and visibility	- Can be improved by kitting, as only kit containers, instead of a wide array of part number-specific containers, need to be delivered to the assembly		- In order to achieve high-quality kits, accurate information needs to be available in the kit preparation area regarding which parts should be included in each kit - If kit preparation is performed downstream of the main in-plant storage, the materials flows from storage to kit preparation area needs the same level of control as the materials flows from storage to assembly line when continuous supply is used
	- Can be improved by kitting, as it is easy to anticipate when a new delivery to the assembly stations is necessary, assuming that the kits are delivered according to the sequence of the assembly objects		
	- Control of materials deterioration can be improved by kitting if the number of feeding points is reduced	- The advantages of kitting are especially apparent for part numbers used at more than one assembly station	
	- Can be worsened by kitting in case of “cannibalisation”, where faulty parts from one kit are replaced by parts from other kits, resulting in complicated shortages		- The risk of “cannibalisation” is closely related to the quality with which the kits are prepared
Product throughput time	- Can be reduced by kitting because of a higher share of value-added time in assembly; related to man-hour consumption in assembly, as described above		
Ergonomics	- Ergonomics in assembly can be improved by kitting if the space-efficient parts presentation can enable parts being presented closer to the assembly object	- Ergonomics risks are greater for parts that are heavy and unwieldy	- The advantages of kitting are especially apparent if continuous supply cannot be performed by use of small unit loads
	- Ergonomics in materials supply can be worsened by kitting because of the additional handling associated with the kit preparation	- Ergonomics risks are greater for parts that are heavy and unwieldy	- When continuous supply cannot be achieved without repacking, the additional handling associated with kitting can be offset
Investment cost	- Can be lower with kitting if the space-efficient parts presentation can enable a shorter assembly line		
	- Can be higher with kitting if process support such as pick-to-light or pick-to-voice is installed to ensure quality in kit preparation		

5.2 The choice between kitting and continuous supply revisited

Expanding on the results of Chapter 4 and the discussion presented in Section 5.1, Section 5.2 links the findings of the thesis back to the thesis aim, as presented in Section 1.4: "The thesis aims to provide knowledge of how the configuration and the context of the in-plant materials supply system should be considered when a choice between kitting and continuous supply is made".

It is clear that there is a considerable complexity associated with a choice between kitting and continuous supply, both because of the multitude of performance areas that can be affected by which of the two materials feeding principles is used and because of the interrelations between the materials feeding principles and the configuration and the context of the in-plant materials supply system. In order to consider all performance areas and interrelations, it seems that a structured process could be useful. Section 2.4 presented four design processes that have been suggested for how complex systems, such as production systems or materials supply systems, should be designed. Neither of the design processes reviewed in Section 2.4 includes the choice between kitting and continuous supply in any detail. However, a similar type of process should be possible to apply to the choice between kitting and continuous supply. In the text below, a design process for an in-plant materials supply system is outlined, where the choice between kitting and continuous supply is an integral part. The outline of the design process is illustrated in Figure 5.2.

Wu (1994) suggests that when designing a production system, the existing system, if there is one, should first be analysed, and thereafter, objectives should be set for how the system should perform. In line with the suggestions of Wu (1994), an analysis should be made both of the existing in-plant materials supply system and of its context before a choice between kitting and continuous supply is made, and based on this analysis, objectives should be set for how the in-plant materials supply system should perform. If there is no existing in-plant materials supply system, there are still, most likely, a number of aspects that need to be considered, for example based on planned production volumes, the facility layout or plans for how the assembly stations should be arranged. Applying the logic of the design processes suggested by Bennett and Forrester (1993), Wu (1994), Bellgran (1998) and Johansson (2006), as presented in Section 2.4, the choice between kitting and continuous supply should be part of an iterative process, where the configuration of the in-plant materials supply system is defined gradually.

The objectives for how the in-plant materials supply system should perform can be expressed in terms of priorities between the performance areas identified in the thesis, as presented in Chapter 2 and listed in Table 5.1. These priorities should be decided in relation to strategic considerations within the company and should consider the existing in-plant materials supply system and its context. For example, the length of the assembly stations or of the assembly line may restrict the space available to present parts, making the space-efficient parts presentation that kitting can enable important. Similarly, when large amounts of part numbers need to be presented at each assembly station, space-efficient parts presentation, associated with kitting, may be prioritised. Conversely, in case the space availability at the assembly stations is not a restriction, but instead little free space exists where kit preparation could be performed, it may be necessary to use the relatively direct materials flows, from storage directly to assembly, that are generally associated with continuous supply.

In the process of generating a configuration of an in-plant materials supply system, including the choice between kitting and continuous supply, the relations illustrated in Figure 5.1 and in Table 5.1 are useful to consider. Focusing on the information presented regarding the performance areas that are most highly prioritised after the initial analysis of the existing system, Table 5.1 can be used to gain an initial idea of whether kitting or continuous supply is more suitable to use, considering both the configuration and the context of the in-plant materials supply system. Thereafter, the information presented in the table regarding the other performance areas should be considered when a preliminary, conceptual configuration of the in-plant materials supply system is generated, so that overall performance of both in-plant materials supply and assembly is satisfactory. As discussed in Section 5.1.4, in case several performance areas are considered important, which is most likely the case, a combination of kitting and continuous supply may be suitable to apply, so that some part numbers are supplied by kitting and others by continuous supply.

As stated above, the configuration of the in-plant materials supply system can be defined gradually during an iterative process. The iterative process should include the evaluation of the suggested configuration in relation to the prioritised performance areas. During the process, changes can be made both to the suggested choice between kitting and continuous supply, so that different combinations between the two materials feeding principles are proposed, and to the rest of the in-plant materials supply system. Throughout the process, the relations presented in Figure 5.1 and the information presented in Table 5.1 should be considered.

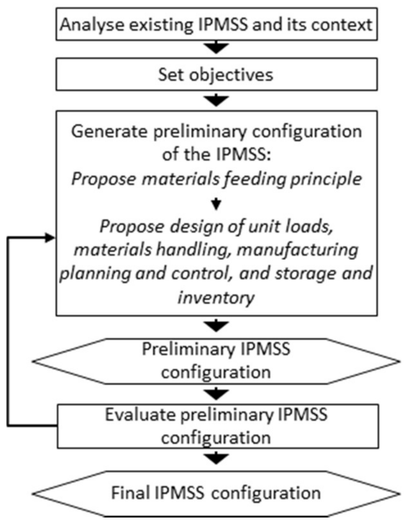


Figure 5.2 *The suggested outline of a design process for an in-plant materials supply system (IPMSS)*

It is important to consider whether a choice between kitting and continuous supply is made in relation to an existing in-plant materials supply system, or in relation to a system that has not yet been put to use. In case the configuration of the in-plant materials supply system is already decided to a large extent, attention must be paid to how well a potential change of materials feeding principles can fit with the existing configuration, or what cost and effort would be required to achieve fundamental changes to the entire in-plant materials supply system and, potentially, to its context. If, instead, the choice between kitting and continuous supply is made before the in-plant materials supply system is put to use, there are better possibilities of achieving an overall solution that corresponds in the best possible way to the performance areas that the company has prioritised. For example, in case 1.1, where kitting was introduced in a context where it was not possible to adapt the assembly plant layout, the space that the introduction of kitting made available at the assembly line could not be effectively utilised by the case company. If it had been possible to adapt the layout of the assembly plant, space could most likely have been better utilised. Correspondingly, if the assembly plant layout has already been decided and has been adapted for materials supply by kitting, it may be difficult to use continuous supply, as this might be associated with a need to prolong the assembly stations or the assembly line in order to be able to present all part numbers (see Deechongkit and Srinon, 2009). Hence, the benefits of changing from one of the two materials feeding principles to the other are likely to be limited, assuming the in-plant materials supply system and its context, for example in terms of the layout of the assembly plant, have been adapted to the first principle.

As was described in Section 1.3, the choice between kitting and continuous supply is in practice often based on simplified guidelines. The findings of the thesis, as summarised in Table 5.1, can be useful in the creation of these guidelines. Similar to the process described above for how a choice between kitting and continuous supply can be made, priorities need to be made between different performance areas before the guidelines can be developed. These priorities should reflect strategic considerations and, to the extent it is possible, the configuration and the context of the in-plant materials supply system where the guidelines are to be applied.

The priorities made between performance areas can have a considerable impact on the guidelines. For example, if overall man-hour consumption in assembly and materials supply is prioritised, the guidelines will most likely favour the use of continuous supply. Guidelines like these could state that continuous supply should be used to the greatest extent possible and that kitting should only be used if continuous supply is not feasible, for example due to lack of space at the assembly stations. As found by Hanson and Johansson (2007), this is the general approach used within the Swedish automotive industry. If, instead, flexibility is prioritised, the guidelines are likely to favour kitting instead of continuous supply, as kitting can enable improved flexibility in terms of volume and mix.

Most likely, the guidelines will include considerations of more than one performance area. For example, as discussed in Section 5.1.4, if continuous supply is used for parts with few variants and kitting is used for parts with many variants, a certain balance can be achieved between the performance areas of man-hour consumption, quality and assembly support, and space requirements. An approach like this could be used for formulating guidelines for which parts should be supplied by which materials feeding principle. What should be regarded as “few” and “many” variants could then be decided based on local conditions within the assembly plant where the guidelines are to be applied, considering, for example, assembly cycle time and length of assembly stations. In line with the findings of the thesis, the guidelines could further reflect general characteristics of the in-plant materials supply system, such as where it is possible to perform kit preparation and whether or not systems are available to support quality in the kit preparation.

5.3 Contributions of the thesis

The findings of the thesis are directly applicable in the choice between kitting and continuous supply and in the design process of an in-plant materials supply system. In addition to providing a contribution to industrial practice, the thesis also provides a contribution to theory. As presented in Chapters 1 and 2 of the thesis, the previous literature addressing the materials feeding principles of kitting and continuous supply has not been sufficient to fully support a choice between these two materials feeding principles. The thesis addresses some of the shortcomings in the existing literature.

It is normally difficult to anticipate the performance associated with the use of kitting and continuous supply (Hua and Johnson, 2010). This is because the performance is linked not only to the materials feeding principle, but there are links also to the configuration of the in-plant materials supply system as a whole and to the context of the in-plant materials supply system. As presented in Chapter 2, most of the reports that exist of performance-related effects associated with kitting and continuous supply are very brief and do not provide much detail regarding why these effects arise. There is little written about how the effects are related both to the configuration and to the context of the in-plant materials supply system.

In addition to a number of brief statements that exist in the literature regarding the effects of using kitting and continuous supply, a number of models have been suggested that can be used to compare the performance associated with the two materials feeding principles (see Bozer and McGinnis, 1992; Battini et al., 2009; Caputo and Pelagagge, 2011; Limère et al., 2011). As described and discussed in Section 2.5, the suggested models have the considerable benefit of offering the possibility to make quantitative comparisons between the two materials feeding principles. However, as further found in Section 2.5, the models are limited in terms of the number of performance areas they include and they are based on a number of simplifications. Furthermore, to be effectively applied, the most comprehensive of the models require very detailed input, which can often be difficult to attain.

Instead of developing a model for quantifying the effects of using kitting and continuous supply, the thesis has used a largely qualitative approach and has had a broad scope of the in-plant materials supply system. The thesis has striven not to make simplifications, but instead to identify and consider the interrelations that exist between the materials feeding principles and the rest of the in-plant materials supply system and its context. Based on an extensive review of the existing literature, complemented by detailed empirical studies, the thesis provides a structured and thorough account of kitting and continuous supply and the effects of using these principles, depending on the configuration and the context of the in-plant materials supply system. This has previously been lacking. The structured and thorough account presented in the thesis contributes to an understanding of the benefits and drawbacks of kitting and continuous supply and the applicability of each of the materials feeding principles, and it constitutes a solid basis for future research related to these two principles.

Moreover, as found in the thesis, the choice between kitting and continuous supply cannot be made isolated from the rest of the in-plant materials supply. Instead, the choice between kitting and continuous supply is a tightly integrated part of the design process of an in-plant materials supply system. Previous publications have, to a large extent, treated the choice between kitting and continuous supply as an isolated decision. In relating the choice between kitting and continuous supply to the design of an in-plant materials supply system, the thesis has suggested that a broader approach should be used.

5.4 Discussion of the generalisability

The current section discusses the extent to which it is possible to generalise the findings of the thesis beyond the settings where the research was performed. As was stated in Section 3.4.3, in the discussion of the external validity of the research, case study research relies on analytical generalisation instead of statistical generalisation (Riege, 2003; Yin, 2009).

All of the empirical studies have been performed within OEMs within the Swedish automotive industry. Corresponding to the scope of the thesis, the studied companies all perform mass-customised, mixed-model assembly. Within the automotive assembly industry, there are large similarities between most assembly plants in terms of overall assembly approach, production volumes, product variety and part characteristics. Accordingly, at least within the automotive assembly industry, the findings of the thesis should be possible to generalise. However, the generalisability should be greater than this.

The thesis has used the existing literature, drawing on experience from a large number of industries, as a basis to describe the relations between materials feeding principles and performance, considering the configuration and the context of the in-plant materials supply system, as illustrated in Figure 5.1. The empirical data of the thesis have been used to confirm and elaborate on these relations. Hence, at least the analytical model illustrated in Figure 5.1 can be generalised beyond the automotive industry.

In addition to being based on theory, all studies in the thesis include careful descriptions of the contexts where they have been conducted, so that the findings can be interpreted in relation to these contexts. By considering the context in which the in-plant materials supply system is operating, as well as the configuration of the in-plant materials supply system as a whole, the generalisability of the thesis findings is increased. In line with this reasoning, it should, to a large extent, be possible to generalise the findings of the thesis even beyond the context of mass-customised, mixed-model assembly. For example, the cycle times and the amount of part numbers displayed at each assembly station are aspects that are considered in the thesis. Accordingly, the thesis can support the choice between kitting and continuous supply even in contexts where cycle times are long and the amount of different part numbers displayed at each assembly station is small, i.e. contexts that are not typical to mass-customised, mixed-model assembly.

5.5 Areas of interest for future research

There are several areas where the research presented in this thesis could be expanded. Accordingly, the current section provides a discussion regarding research that could be undertaken in the future.

The fact that kitting and continuous supply can often be combined has received some attention in the thesis. In paper II, the effects that such an approach can have on man-hour consumption in assembly were studied. However, there are several other aspects that should be considered in relation to how such a combination should best be achieved. Since a combination of kitting and continuous supply holds a potential to combine benefits of both materials feeding principles, it is likely that such an approach can be suitable in many contexts. However, there is little support within the existing literature regarding how the proportion of each principle should be decided or regarding which type of parts should be supplied by which principle. Overall, there is a need for further studies that can support the development of guidelines regarding how combinations of kitting and continuous supply should be achieved, in terms of which parts should be supplied by which principle. Considerations of this type should include product- and part-related factors, such as size and weight of the parts and the number of different part variants, production-related factors, such as production volumes, as well as layout-related factors, such as the size of the assembly stations. It is also important to consider the potential impact on all performance areas. For example, depending on which parts are supplied by kitting and which by continuous supply, the support provided to the assemblers may vary.

As described in Section 2.1.1, kitting and continuous supply are not the only materials feeding principles that exist. Batch supply and sequential deliveries of single parts can also be used. In future research, the choice between kitting and continuous supply could be expanded to include these materials feeding principles too, including potential combinations of the different materials feeding principles.

The man-hour consumption is, as has been stressed in the thesis, an important performance area to consider in relation to the choice between kitting and continuous supply. In all case studies, as well as in all results and discussions so far in the thesis, the man-hour consumption associated with the kit preparation has been found to be one of the main disadvantages associated with kitting. It is therefore relevant to consider the possibilities of automating the kit preparation, and the possibility to thereby eliminate the man-hour consumption of this activity. This option has received some attention in the literature (Seller and Nof, 1986; Sellers and Nof, 1989; Tamaki and Nof, 1991), but the use in practice is limited. Automation is often associated with considerable investment cost, which may deter industry. Especially in order to prepare kits that contain parts that vary considerably in their dimensions, a high level of sophistication is required from the automation equipment, which is likely to be associated with a high cost. However, as technical development progresses in the area of automation, prices are likely to decrease, making automated kit preparation a viable alternative. Research in the area of automated kit preparation would be useful to achieve this. This research would, to a large extent, need to focus on the technical aspects of automation, but it would also need to consider the requirements of the assembly and of the materials supply.

There were a number of performance areas that were brought up in Chapter 2 that were not addressed in the empirical studies of the thesis. In the empirical studies, no comparisons were made between how kitting and continuous supply perform in the areas of control and visibility, product throughput time, ergonomics or investment cost. All of these performance areas could be studied further in future research. Especially the performance area of control and visibility seems to be relevant to study further, as it is brought up in several publications on kitting and continuous supply, as presented in Chapter 2.

It was not possible to fully establish the effects on product quality in any of the case studies. Accordingly, the thesis has not been able to provide conclusive evidence regarding the quality-related performance impact associated with the choice between kitting and continuous supply. Since this is a potentially important aspect in relation to the choice, there is a need for further studies that focus on product quality in relation to the use of kitting and continuous supply, respectively. Clearly, when kitting is used, the product quality is related to the quality of the kit preparation. Quality-assurance in kit preparation is an area that has not received much attention in the research literature, but because of its importance in relation to the performance of materials supply by kitting, this area should be addressed in future studies.

As stated in Section 1.3, the complexity characterising the choice between kitting and continuous supply makes it difficult to formulate straightforward recommendations regarding which materials feeding principles should be used when. Both the configuration and the context of the in-plant materials supply system should be considered and in order to take all relevant factors into account, a comprehensive investigation may be required for each choice that is made. Section 2.4 discussed the benefits of using a formal design process when making a choice between kitting and continuous supply and Section 5.2 presented an outline of such a design process. The creation of a more detailed design process could be part of future research efforts.

6 Conclusions

The thesis has focused its attention on the choice between the two materials feeding principles of kitting and continuous supply within in-plant materials supply in mass-customised assembly. This chapter constitutes the conclusions of the thesis and presents, concisely, the findings of the thesis and how they were developed.

A choice between kitting and continuous supply in relation to an in-plant materials supply system can have significant impact on the performance of both in-plant materials supply and assembly. However, existing knowledge, both within industry and within research literature, has not been sufficient to fully support the choice. Therefore, the thesis has sought to expand the knowledge of the two materials feeding principles of kitting and continuous supply and to provide support to the choice between these two principles within industry.

The research has been based on three research questions, which have had a common goal of expanding the knowledge of which performance effects can be expected based on whether kitting or continuous supply is used, and based on how each principle is used. To answer the three research questions, several research studies have been performed, most of which have been case studies. One experiment has also been performed. The research studies have been presented in six research papers, which are included in the thesis. Research question 1, focusing on the performance impact related to whether kitting or continuous supply is used, was answered based on papers I-III in the thesis. It was found that there are several effects associated with whether kitting or continuous supply is used and that these effects are, to a large extent, related to the configuration of the in-plant materials supply system as a whole. Research question 2 focuses on in-plant materials supply by kitting and addresses the issue of how the location of the kit preparation can affect in-plant materials supply performance. Research question 3 focuses on in-plant materials supply based on continuous supply and, specifically, on how the size of the unit loads used can affect man-hour consumption in in-plant materials supply. Based on four case studies, presented in papers V and VI of the thesis, it is clear that the relation between the unit load size and the efficiency of the in-plant materials supply is very closely tied not only to the size of the unit loads, but to the overall configuration of the in-plant materials supply system.

Overall, based on the findings of the thesis, it is clear that both kitting and continuous supply are associated with both benefits and drawbacks. It is also clear that the performance associated with kitting and continuous supply is affected both by how the materials feeding principles are applied, in terms of the configuration of the in-plant materials supply system as a whole, and by the context of the in-plant materials supply system. Hence, because the relative performance associated with kitting and continuous supply can vary between different applications, it is not surprising that, in the existing literature, there exist contradictory reports of which relative effects can be associated with each of the two principles.

When making a choice between kitting and continuous supply, since the performance of an in-plant materials supply is dependent not only on which materials feeding principles are used, a careful analysis should preferably be made of how a materials supply system based on each principle should be configured and what kind of performance could then be expected, both in materials supply and in assembly. The findings of the thesis offer valuable input to this analysis, by providing insight into what performance can be expected when either materials feeding principle is used. The thesis not only identifies the potential performance impact associated with each materials feeding principle, but it also provides insight into how and in what contexts this performance impact arises. Thereby, the thesis provides a contribution to industrial practice. The thesis also fills a gap in the literature, as few detailed studies previously existed that could be used to foresee the performance impact associated with a choice between kitting and continuous supply. In this context it is important to acknowledge the specific insight that has been provided regarding how the performance of an in-plant materials supply system can be affected by the location of the kit preparation, assuming kitting is used, or by the size and type of the unit loads used, assuming continuous supply is used.

When making a choice between kitting and continuous supply, it is not sufficient to be aware of the performance impact that this choice will have, but it is also necessary to prioritise between different performance areas. As the two materials feeding principles are associated with both benefits and drawbacks, it is unlikely that any choice will result in optimal performance in all performance areas. The priorities are likely to be linked to the conditions within the assembly plant in question, or even to different areas within the assembly plant.

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