Energy-, cost- and time efficient in-plant material supply systems

Project within Hållbar produktionsteknik

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Content

FFI in short

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1. Executive summary

The performance of the in-plant materials supply is of central importance to the performance of a production system as a whole. Yet, the knowledge of how in-plant materials supply systems should be designed is today limited, not least in relation to the considerable changes that are taking place in industry today, involving the increased utilisation of lean production principles. In present research studies and literature there are few reports from the area. Lack of knowledge constitutes a hindrance for the development of competitive production systems. The problem area is extensive and includes energy, cost and time efficiency, as well as work environment. The objective of the project is to develop knowledge to understand and evaluate in-plant materials supply system impact efficiency, flexibility and ergonomics in production systems.

Focus in the project is 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 be 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.

The research has been conducted mainly in the form of case studies at assembly plants within the Swedish automotive industry. Complementing the case studies, two experiments have 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. Separate studies have studied picking system support. 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 research results 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.

2. Background

The project addresses a research area of substantial relevance both to industry and to academia. The performance of the in-plant materials supply is of central importance to the performance of a production system as a whole. Yet, the knowledge of how in-plant materials supply systems should be designed is today very limited, not least in relation to the considerable changes that are taking place in industry today, involving the increased utilisation of lean production principles. Lack of knowledge constitutes a hindrance for the development of competitive production systems. The problem area is extensive and includes energy, cost and time efficiency, as well as work environment.

The project is based on the recognition of the in-plant materials supply system as an integral part of a Lean Production system, with a pull-controlled production and continuous value flows. The way in which the materials supply is performed is important not only for the performance of the materials supply operations themselves, but can also have a decisive impact on the performance of the receiving assembly operations (Wänström and Medbo, 2009).

From a working environment and ergonomics perspective, manual material handling is one of the most widely studied risk factors for musculoskeletal disorders (MSDs) such as low back pain – the worlds most expensive work place injury (Bernard 1997). Previous research in Swedish industry has shown that the selection and implementation of material supply strategy has substantial impact on the biomechanical loads on the operator and hence their risk of musculoskeletal injury (Neumann et al. 2006).

Within Swedish industry, the issues of supporting assembly operations have received less attention and the design of the materials supply has instead been influenced by a focus on economies of scale. This has resulted in large transport quantities and components being presented at the assembly stations in large packaging and in storage type racks and contrasts to the strive for Lean Production based on continuous flow with small batches.

Considering the increasing demand for vehicles with alternative drivetrains, necessary in the development towards sustainable transport and traffic systems, requirements for flexibility in materials supply are becoming increasingly pressing, as the number of product variants assembled in each production plant is likely to increase. Thus, the design of the materials supply system must support the efficient handling of a large number of component variants, both in the materials supply operations and in the assembly operations.

Among the different aspects of the in-plant materials supply is the choice of materials feeding principle, where continuous supply (also known as line-stocking), batching, sequenced deliveries, and kitting (also known as set parts system), are the most common options. For the project, continuous supply, kitting and sequenced deliveries combined with kitting, are by the participating companies seen as the options of most interest for the Swedish automotive industry.

An important aspect of the in-plant materials supply is to enable manufacturing flexibility. Expansion potential, volume flexibility, and product mix flexibility are all related to the free space which is potentially available among the component racks. Utilising potential space reduction will facilitate energy efficiency.

Kitting is, internationally, becoming more and more used in industry. The knowledge is, however, lacking regarding which situations and for which components kitting should be applied, as the full effects of using kitting have not yet been established.

For the use of kitting, an additional motive can be product quality, as the use of kits ensures that the assembler does not by mistake choose the wrong components to assemble. Another related motive is assembly training with reduced learning time, which can be facilitated by the use of kitting (Medbo, 1999). Studies from Swedish automotive companies have reported extensive potential for increased efficiency and flexibility (e.g. Wänström and Medbo, 2009, Engström et al. 2004). There are also indications that kitting can result in considerable improvement from an ergonomic perspective (Wänström and Medbo, 2009, Engström et al. 1995, Neumann et al. 2006).

There is, without doubt, a great potential for improving the materials supply systems used in Swedish automotive assembly industry today. There are a great number of options available for designing these systems, but the knowledge of several of the options is very limited.

A successful and widespread utilisation of principles and techniques such as continuous supply, kitting, tugger train transports, and minomi requires that the understanding and the knowledge about the concepts are developed. There is a need for models explaining how the concepts influence operations.

From investigations of the needs of the four automotive companies involved in the project, and in agreement with the theoretical background presented above, three main areas were identified which are of specific importance for improving the performance of the materials supply operations:

Long-term strategy: Knowledge is needed regarding how a long-term strategy for the in-plant materials supply system should be formulated and which aspects that should be included.

Continuous supply: The materials feeding principle of continuous supply is the one most frequently utilised within the Swedish vehicle assembly companies (Hanson and Johansson 2007). Yet, comparing internationally, the Swedish industry adoption of continuous supply is less effective. Questions exist regarding which types and sizes of packaging, if any, should be used and how they should be handled.

Kitting and sequencing: The interest for kitting as materials feeding principle is growing in the Swedish automotive industry. Sequenced deliveries are already applied within industry today and are now increasing in combination with kitting. However, experience and knowledge are limited regarding the use and application of kitting. Different and to some extent contradictory reasons motivating kitting are reported from both industry and researchers. This unclear picture of kitting has reinforced need to tackle this problem area.

In designing the in-plant materials supply system, including the choice of materials feeding principle, the performance of the materials supply system should be considered with regard to several aspects. Efficiency in terms of time and cost is a central aspect for achieving competitive operations. Aspects of working conditions (principally ergonomics) and energy efficiency are vital, considering the ambition of the companies to achieve sustainable production systems. Flexibility to handle variations in terms of volume, and mix, as well as product introductions and engineering changes is of importance. Furthermore, considering the importance of the in-plant materials supply system for the performance of the whole production system, robustness is a necessity.

3. Objective

The objective of the project is to develop knowledge to understand and evaluate in-plant materials supply system impact on the following performance areas:

- Cost, time, and energy efficiency
- Volume and variant flexibility
- Health and safety and ergonomics
- Support to the assembly operations

The knowledge regarding the design of in-plant materials supply systems is today limited. Development of theory and models will facilitate design of in-plant materials supply system with outstanding performance. It is important to recognise that the materials supply system should not be viewed as a separate entity, but should be designed with reference to the assembly operations which it is to support and also to other relevant aspects of the manufacturing system. It is therefore necessary to understand which contextual preconditions that are of importance and how they affect the performance of the in-plant materials supply system. In a Lean Production context, where the value-added time, in a value flow, is in focus, the in-plant materials supply system should support the assembly operations as far as possible based on its requirements. Knowledge is therefore needed of which the requirements of the assembly process are and how the materials supply system can meet them.

As identified in the project background presented earlier, a central issue within the design of an in-plant materials supply system is the choice of materials feeding principle. This choice has a considerable impact on practically all other aspects of the in-plant materials supply system and is also highly interconnected with how the components are presented at the receiving work stations. There are therefore several questions that need to be taken into account in relation to the choice of materials feeding principle. The choice of materials feeding principle involves design of many parts and elements such as packaging type, ordering system, means of transport, handling processes, which all need to be considered.

4. Project realization

The project was organized by theoretical and empirical studies on the basis of the participating companies’ problem areas. Practitioners and researchers that jointly formulated the research project application developed an implementation plan which meant that a number of case studies were conducted at the various companies. Some case studies were conducted at a single production system, while others covered several business and production systems. The case studies were chosen based on the project's purpose and the formulated research questions. Through a literature review a theoretical framework has been developed that positions and relates the project's research into existing knowledge and previous studies. Developing the theoretical framework was an ongoing activity throughout the project, although the emphasis is on the project's beginning. Based on the developed framework, a set of different theoretical frameworks or models were developed and then used in the case studies as an aid to understand, analyse and synthesize the results. In addition to the case studies, two experiments were also carried out.

Intermediate and final results from case studies were discussed at workshops with business representatives and researchers involved in the case studies as well as in open workshops. As both practitioners and researchers have conducted case studies collaboratively, although to different extents, implementation and utilization was a direct result of the different case studies. Meanwhile have of course researchers' results also meant scientific merit through publications in journals and presentations at conferences. As shown in the results chapter below, the dissertation made possible by the project meant that the various deliverables have been merged into both practically useful as scientifically essential knowledge.

Within the different areas which the project have addressed, the following studies were conducted:

- The first study consisted of an experiment at Saab where kitting where compared with the in Swedish industry common materials supply policy of continuous supply.
- Three studies on kitting were conducted at companies that were introducing kitting in their assembly operations: Volvo Powertrain, Saab and Scania. All studies include a mapping of assembly and materials supply, both before and after the introduction of kitting.
- A kitting-focused study was conducted in order to identify how the material supply system performance is affected by the location where kits were prepared. Through three case studies from Scania, Saab and Pininfarina have three fundamentally different locations of kit-preparation been studied and compared.
- Case studies on efficiency and flexibility in picking and design of picking operations, both for kitting and sequenced delivery of individual items have been carried out at Volvo Cars in Gothenburg and at Volvo Construction Equipment in Hallsberg.
- A review of practices used in the automotive industry to provide information to pick pickers have been conducted. Based on the survey, picker support systems were developed that are being tested by experiment.
- Material Control of physical flows have been studied through case studies at Volvo Construction Equipment and Scania.

5. Results and deliverables

The presented results focuses on the material supply principle kitting that the project deemed the most interesting area for both research and industry. Kitting is related to the conventional method, continuous supply.

The materials feeding principles that are used constitute an integral part of the in-plant materials supply and can affect a large number of performance areas of both in-plant materials supply and assembly.

In assembly, the use of kitting to present parts can reduce man-hour consumption compared to continuous supply. Within research 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 since no time needs to be spent searching for parts. The project has shown that both of these aspects are significant in relation to the man-hour consumption in assembly. One of the studies of the project showed that 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 other studies of the project, 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.

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, 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 the project, 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.

The studies of the project indicated that parts presentation in kits can have 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. 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 one of the studies, some difficulties had, however, been registered related to how the parts were presented within the kits.

When the kits lacked formal structure, searching for parts was sometimes necessary and some parts could be confused. It seems that a structured kit can offer better support to the assemblers than a kit without formal structure.

In the cases studied, 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 if these mistakes are discovered and corrected at the assembly stations, and thus does not impact on final product quality, resources are 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.

In previous research literature, kitting has been stated to be associated with a higher level of flexibility than continuous supply. The results of the project provide support for this notion. Because of the space-efficient parts presentation that kitting enables, illustrated in several of the case studies of the project, 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. 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, 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 project has further found that, compared to continuous supply, kitting can be associated with a greater flexibility for rebalancing an assembly line, as it is 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. The level of flexibility is, however, related to the configuration of the materials supply system. It seems that the more different kits that are used at an assembly line, the more will the flexibility be restricted, especially if kit containers are used that have specific, fixed positions for each part.

The project has found that the performance impact that can be derived from which materials feeding principle is used is strongly related both to the overall configuration of the in-plant materials supply system, of which the materials feeding principles can be seen as one dimension, and to the context of the in-plant materials supply system. Moreover, it is important to acknowledge that there are numerous different performance areas, which can be affected differently by the choice of materials feeding principle. These relations are illustrated in the figure 1.

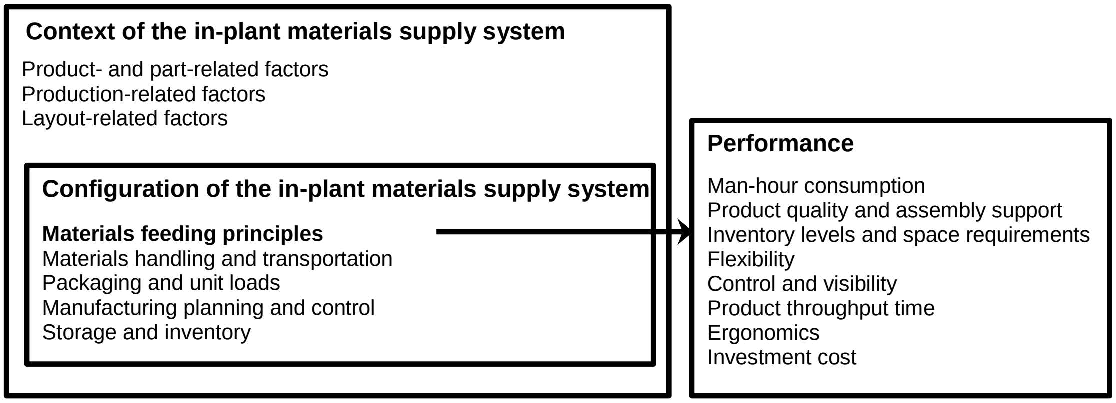

Figure 1: Overview of the relations between materials feeding principles and performance, considering the configuration and the context of the in-plant materials supply system

The configuration of the in-plant materials supply system can be defined gradually during an iterative process, as developed in the project and illustrated in the figure 2. 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.

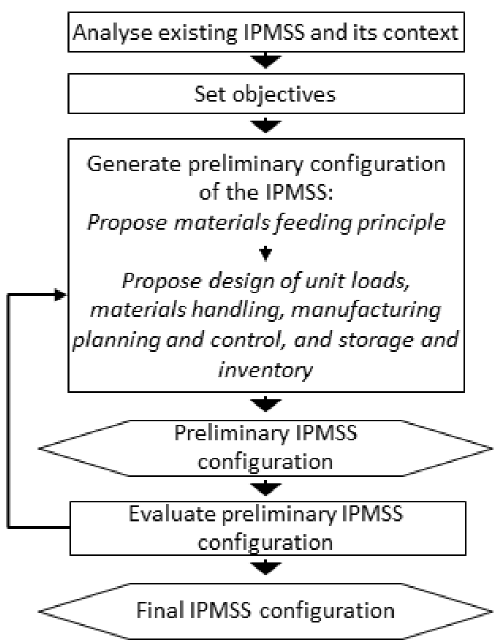

Figure 2: The suggested outline of a design process for an in-plant materials supply system (IPMSS)

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.

As mentioned above, it is essential that the correct details are picked together in the kits if the positive effects of kitting are to be obtained. While it is essential that the resource consumption is as low as possible. Since picking of parts in the automotive industry material supply is increasing, support for efficient picking operations have been actualized as an increasingly important area. Picking is done not only for kitting, but also mainly for sequencing and repackaging into smaller packages. The project included studies that show large differences in prerequisites and design of different picking systems. The purpose was to obtain an understanding and knowledge of picking operations to provide a basis for the design of efficient picking, which covers both the time spent by the operator as the quality of picking operation.

Mapping and studies were conducted of picking principles, operator time usage, physical design of the picking station or storage, support and tools for picking operations and picking quality. Different methods for picking support were studied, such as paper pick lists, picking information on terminals, wireless voice and communication (pick-by-voice) and different types of arrangement with lights and lamps (pick-by-light). The results do not cover the area as a whole, while providing guidance and suggest areas for further research and development.

The studies indicated large differences in performance between the different picking systems. Both quality and resource consumption differ. Big differences in prerequisites of which type of components, product variety, production volume variation, layout, skills, etc. affects to a large extent the outcome. Furthermore, the design of the picking operations is of course in itself essential. The picking system used to provide information to the picker vary, the ongoing development of technology is fast and there is no common industry standard or consensus among practitioners as well as researchers, about what is the right support in different situations. Studies with picking supported by both pick-by-voice and pick-by-light has shown good results. Pick-by-voice is appropriate when the components to pick are so big (and by that the package) that the picker has to walk some steps between each pick operation. At small distances, pick-by-voice communication causes some delays for the picker. Pick-by-voice also means a good opportunity to follow up conducted picks, which among other things is used to reduce picking errors and for time-balancing the picking work. Pick-by-light systems predominate in the material supply to assembly abroad, which the project studied in the Japanese automotive industry. For combinations of assembly station layouts and components that created short travel distances could time-efficient picking be observed. Both pick-by-voice and pick-by-light systems have however been shown to have poor flexibility when changes need to be made, such as moving or adding components in a picking facade. The proposed improvements in picking procedure suggested by employees is difficult to implement, which can lead to a discrepancy between how the work is described and how it is carried out in reality. The companies involved in the project have implemented and are implementing various types of picking support.

By generating knowledge of which performance-related effects can be expected from different configurations of the in-plant materials supply system, such as the choice of materials feeding principle, the project supports the design of efficient, high performing production systems. Specifically, the results of the project can support increased cost efficiency, product quality and flexibility in both in-plant materials supply and production, thereby supporting the competitiveness and sustainability of the Swedish vehicle assembly industry.

One of the main advantages of the materials feeding principle of kitting, which was a main focus areas of the project, is that flexibility can be increased, both in relation to production volumes and product variety. This is in line with the anticipated need for production systems to allow for vehicles with different types of drivetrains (e.g. vehicles with traditional internal combustion engines, electrical vehicles, hybrid vehicles) to be assembled in the same facilities, potentially in mixed sequence.

6. Dissemination and publications

6.1 Knowledge and results dissemination

Due to that the project execution has been based on case studies jointly participated by practitioners and researchers, the results have been automatically implemented in the companies' activities. Several case studies have also been linked to various development projects in the companies which resulted in an expectation of change which thus facilitated the implementation of the project results. Through project meetings have results from different studies been discussed within the project team.

Continuously during the project, a number of workshops focusing on various problem areas have been organized. During the workshops, project results have been presented and discussed with participants from across the automotive industry, research institutes and universities. In addition, the project results have been presented at industry conferences and trade exhibitions. Interest in the project's area of concern has been and is still great. The main reason is surely that many companies are experiencing both problems and uncertainty regarding how these problems should be addressed and resolved. Existing guidelines and standards does not often lead to improvements. Furthermore, the differences in how materials supply systems have been designed in Sweden compared to many other countries is large, a trend accentuated in recent years. These differences also affect the interest of the industry to embrace project results.

In education, the project results continuously conveyed knowledge to the students at Chalmers who take courses given by the Department of Logistics and Transportation. This applies mainly to the courses "Lean Production" at International Masters Programme Production engineering and the, as of spring of 2012, newly developed course "Production flow management" at International Masters Programme Supply Chain Management as well as courses in "Lean production" for professionals in the Chalmers Professional Education. Through courses directed towards professionals, the project results are widely disseminated to both large, small and medium-sized enterprises. Through linkage and cooperation with Produktionslyftet, seven to eight courses, each with 25 participants is conducted per year around the country.

Examples of activities during the project that contributed to the knowledge and dissemination of results:

• Presentations at the Swedish Assembly Forum annual conference in Stockholm

• Participating FFI conferences.

• Organisation of workshops and seminars

• Participation in workshops Automotive Suppliers Group (FKG)

• Dissertations and theses at Chalmers

• Presentations at scientific conferences: European Operations Management (EURoma), Swedish Production Systems (SPS), International Production Research (ICPR), Industrial Systems and the International Scientific Conference on Lean Technologies in Novi Sad.

• Presentations at the logistics cluster meetings

• Seminars at industry conferences and trade shows: Logistics and Transport Fair in Gothenburg, transportation efficiency conference in Gothenburg,

6.2 Publications

Algestam, S., Medbo, L., Wänström, C. (2012), Designing a pull oriented material planning system - human, technical and organizational considerations. *In: Proceedings from the EurOMA Conference*. 1-4 July, 2012, Amsterdam.

Algestam, S., Rosenberg, P. (2011) Supplier consequences of variation in demand planning information: An automotive industry case study. *PLANs Forsknings- och tillämpningskonferens*, Norrköping, Sweden

Andersson D., Hosseini V., Lindström J., Löfberg N., Moazami, A. and Puranik, N. (2010) *Evaluation of line-side material supply alternatives for Volvo Cars, Torslanda plant*. Project in the course Projects in Supply Chain Management TEK275, Chalmers University of Technology."

Andersson, A. And Norman, B. (2013) *Effektivisering av stödprocesser: En studie i lean materialhantering*, Master of Science Thesis, Linköping University (in Swedish).

Hanson, R. (2011) The effects of using minomi in in-plant materials supply. *Journal of*

Manufacturing Technology Management, 22 (1), pp. 90-106.

Hanson, R. (2012) In-plant materials supply: Supporting the choice between kitting and continuous supply. PhD Thesis, Chalmers University of Technology.

Hanson, R. (2012) Valet mellan kitting och kontinuerlig försörjning, *Verkstäderna*, 108(7), pp. 34-36.

Hanson, R. and Brolin, A. (2011) A comparison of kitting and continuous supply in in-plant materials supply. *In: Proceedings of the 4th International Annual Swedish Production Symposium.* 3-5 May, 2011, Lund.

Hanson, R. and Brolin, A. (2013) A comparison of kitting and continuous supply in in-plant materials supply. *International Journal of Production Research,* 51(4), pp. 979-992.

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Hanson, R., Medbo, L., Medbo, P. (2010) Assembly station design - a quantitative comparison of the effects of kitting and continuous supply. *In: Proceedings of the 17th International EurOMA Conference*. 6-9 June, 2010, Porto, Portugal.

Hansson, R. Medbo, L. and Medbo, P. (2010). "Assembly station design - a quantitative comparison of the effects of kitting and continuous supply", *in: Proceedings of16th International Annual EurOMA Conference: Managing Operations in Service Economies.* 6-9 June, 2010, Porto.

Hellman F., Lindahl, B. and Malmberg, J. (2011) *Mixed-model assembly line at Volvo Construction Equipment*. Master of Science Thesis, Chalmers University of Technology.

Johansson, M.I., Wänström, C. and Medbo, L. (2012) Flexibility of Materials Supply

Systems, *In: Proceedings of the 5th International Annual Swedish Production Symposium.* 6-8 September, 2012, Linköping.

Johansson, R. And Söderberg, E, (2011) *Effektivisering och kvalitetssäkring av plockning på Scania*, Master of Science Thesis, Linköping University (in Swedish).

Karlsson, E. and Thoresson, T. (2011) *A comparative study of the material feeding principles kitting and sequencing at Saab Automobile, Trollhättan: creation of guiding principles of which articles to be supplied with kitting*, Master of Science Thesis, Chalmers University of Technology.

Neumann, P. and Medbo, L. (2010) Ergonomic and technical aspects in the redesign of material supply systems: Big boxes vs. narrow bins. *International Journal of Industrial Ergonomics*. 40 (5) pp. 541-548.

Stenberg, M. and Lundgren, E. (2011) *Picking Station Design Considerations for Improved Sequence Picking: A Case Study at Volvo Cars Torslanda*, Master of Science Thesis, Chalmers University of Technology.

Wu, C., Yao, C., Yavuz, D., Xu, H. and Dzinic, J. (2012), *Kitting of low frequent parts in Volvo Cars Torslanda*, Production Project Work in the course IAR057, Chalmers University of Technology.

Internal Company publications (guidelines, education documents etc.)

Brynzér H. (2012) *Interna materialleveranser – Replenishment*, Internal education document, Volvo Car Corporation.

Brynzér, H. (2011) *Part Classification & Repacking time calculation in the Downsizing Process*, Internal education document, Volvo Car Corporation.

Karlsson, R. (2011) *Method development – Secured & efficient kitting and sequencing*, Internal document, Scania CV.

Karlsson, R. (2011) *Quality assured kitting and sequencing: with productivity and ergonomics*, Internal document, Scania CV.

Kubota, Y. (2012) *Scania internal supply methods*, Internal document, Scania CV.

Lindström, K. (2013) *Standardized PRIDE*, Internal document, Scania CV.

Lööv, P. (2012) *Supply timing – 1:2:4 method*, Internal document, Scania CV.

Scania, *Tunga vagnar: utformning och bedömning av tunga vagnar*, Internal document, Scania CV.

7. Conclusions and future research

To a large extent, the research has been based on the ambition to expand 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 achieve this, several research studies have been performed, most of which have been case studies. Two experiments has also been performed. The research studies have been presented in several publications, as presented in section 6.2.

From the project, 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 research 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 project offer valuable input to this analysis, by providing insight into what performance can be expected when either materials feeding principle is used. The project has not only identified the potential performance impact associated with each materials feeding principle, but it has also provided insight into how and in what contexts this performance impact arises. Thereby, the project has provided a contribution to industrial practice. The findings of the project further fill a gap in the research 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.

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.

The fact that kitting and continuous supply can often be combined has received some attention in the studies of the project, but should be studied further. Within the project, 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 research 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.

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. It is not just a question to choose the right feeding principle for a part, but also that the combination of different feeding principles constituting a whole materials feeding system should be high performing. Today we see different feeding principles interfering resulting in long lead times, high total resource consumptions and quality problems. It is thus a need for increased knowledge and guidelines in design of materials supply systems based on combination of feeding principles.

The studies of the project have indicated that the man-hour consumption associated with the kit preparation is of the main disadvantages associated with kitting. It is therefore of interest to study the kit preparation further, seeking ways to reduce man-hour consumption in these operations. At the same time, it is crucial to ensure performance in other performance areas too, such as product quality.

Within the project, it was not possible to fully establish the effects that the choice between kitting and continuous supply has on product quality. Accordingly, the project 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.

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. Within the project, an outline was made of a formal design process. The creation of a more detailed design process could be part of future research efforts.

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