Taylor & Francis
Taylor & Francis Group

Production & Manufacturing Research

An Open Access Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tpmr20

Joint modelling of the order-dependent parts supply strategies sequencing, kitting and batch supply for assembly lines: insights from industrial practice

Frederik Ferid Ostermeier, Jens Jaehnert & Jochen Deuse

To cite this article: Frederik Ferid Ostermeier, Jens Jaehnert & Jochen Deuse (2023) Joint modelling of the order-dependent parts supply strategies sequencing, kitting and batch supply for assembly lines: insights from industrial practice, Production & Manufacturing Research, 11:1, 2200808, DOI: 10.1080/21693277.2023.2200808

To link to this article: https://doi.org/10.1080/21693277.2023.2200808

PRODUCTION & MANUFACTURING RESEARCH
https://doi.org/10.1080/21693277.2023.2200808

Taylor & Francis
Taylor & Francis Group

OPEN ACCESS Check for updates

Joint modelling of the order-dependent parts supply strategies sequencing, kitting and batch supply for assembly lines: insights from industrial practice

Frederik Ferid Ostermeier[a,b], Jens Jaehnert[b] and Jochen Deuse[a,c]

[a]Institute of Production Systems, TU Dortmund University, Dortmund, Germany; [b]Department of Production, BMW Group, Munich, Germany; [c]Faculty of Engineering and Information Technology, School of Mechanical and Mechatronic Engineering, Centre for Advanced Manufacturing, University of Technology Sydney, Sydney, Australia

ABSTRACT

Parts can be supplied from warehouses to assembly lines via several production-order-independent and -dependent parts supply strategies. Order-dependent parts supply strategies sequencing, kitting and batch supply share enough similarities that allow joint modelling in picking order planning and execution, whereas line stocking, just-in-time, just-in-sequence and just-in-sequence kit supply require separate modelling. Joint modelling is the precondition for setting up a software system in industrial practice, covering multiple parts supply strategies efficiently. With similar input–output relations and process steps, joint algorithms can be used. This work presents insights from a software system for sequencing, kitting and batch supply implemented in the automotive industry. The main process steps modelled are order-dependent part requests determination, bundling of part requests to picking orders, scheduling and release, and picking and transportation execution. Given the prevalence of assembly lines, sharing knowledge about successful modelling of parts supply strategies is crucial both for practitioners and researchers.

ARTICLE HISTORY
Received 18 February 2023
Accepted 1 April 2023

KEYWORDS
Parts supply strategies; sequencing; kitting; batch supply; assembly lines

1. Introduction

Parts supply plays an essential role in the efficient operation of assembly lines. Parts can be fed to an assembly line via a multitude of parts supply strategies ensuring the reliable and cost-efficient supply of parts (Müllerklein et al., 2022): reliable in the sense of supplying the requested parts in the requested amount at the requested time (Kilic & Durmusoglu, 2015) and cost efficient concerning material handling, space and storage costs (Limère et al., 2012). Different parts supply strategies differ in many aspects affecting the reliability and cost-efficiency of parts supply: whether the supplied parts are warehouse parts or whether the part requests are based on the demand for production orders, to name but a few. In particular, mixed-model assembly lines, where multiple

CONTACT Frederik Ferid Ostermeier Frederik.Ostermeier@bmw.de BMW Group, Bremer Str. 6, Munich 80807, Germany

different models are produced on the same assembly line, require the usage of different parts supply strategies in order to efficiently cope with the huge amount of different parts to be supplied.

Within this work, analogue to industrial practice and different to some academic works (cf. Schmid & Limère, 2019), a distinction is made between parts supply strategies that supply warehouse parts from inhouse warehouses and those that supply non-warehouse parts directly from suppliers since the modelling of the affected process steps for picking order planning and execution deviates significantly. Important parts supply strategies for warehouse parts are line stocking, sequencing, kitting and batch supply. Non-warehouse parts can be supplied via just-in-time (JIT) supply, just-in-sequence (JIS) supply and JIS kit supply. In addition to these basic strategies, hybrid strategies can be found in industrial practice, which will not be explored further in this work (cf. Kilic & Durmusoglu, 2015). Figure 1 provides an overview of the seven basic parts supply strategies.

With **JIT supply**, non-warehouse parts are supplied in an order-independent way from a supplier directly to a production supply area (PSA) at the Border of Line (BoL) in boxes containing merely parts of a single stock keeping unit (SKU). An SKU is referred to a distinct part number in industrial practice. There is no intermediate storage between the supplier and the stocks at the BoL. The parts are supplied independent of the actual

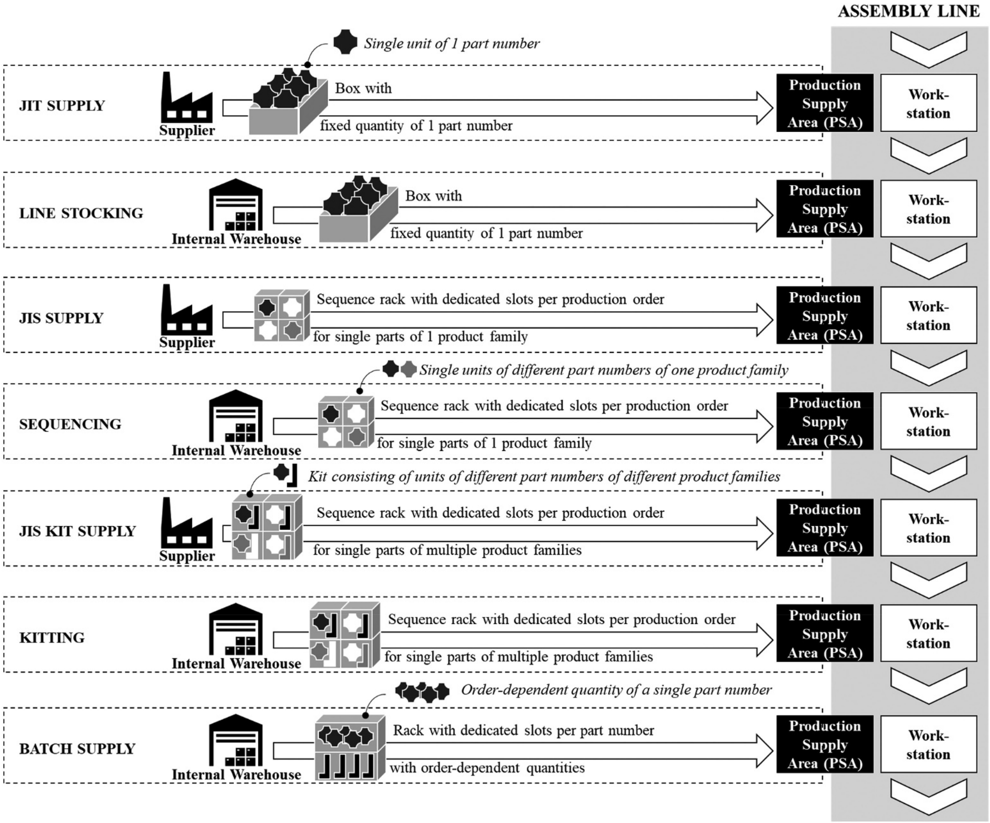


Figure 1. Overview of parts supply strategies.

demands for production in predefined box quantities, and resupply is triggered by a Kanban principle or another replenishment policy, similar to line stocking. JIT supply is especially advantageous for large parts delivered in small quantities within a box, consuming a lot of space such that a direct supply from the supplier becomes advantageous (Müllerklein et al., 2022). However, a direct supply from a supplier might always be subject to disruptions, for instance during transportation.

With **line stocking**, warehouse parts are supplied in an order-independent way from a warehouse to a PSA at the BoL in boxes containing merely parts of a single part number (Schmid & Limère, 2019). These parts are supplied in predefined box quantities and are independent of the actual demands for production orders (Hua & Johnson, 2010; Limère et al., 2012). Supply of a box with new parts is organized with replenishment policies, e.g. using reorder points (Limère et al., 2015) or being triggered when a box at the line becomes empty, following a Kanban principle (Sali et al., 2015). In the automotive industry, line stocking is the most prevalent parts supply strategy due to its simplicity and the low material handling efforts yet coming at costs of a higher space utilization and no time savings during picking of parts by the assembly worker (Baller et al., 2020; Sali et al., 2015). Line stocking is also denoted as continuous supply in academia (Hanson & Brolin, 2013).

With **JIS supply**, non-warehouse parts are supplied in an order-dependent way from a supplier directly to a PSA at the BoL in boxes containing several part numbers of the same part family (Battini et al., 2013). These single parts are put into slots dedicated to each production order being supplied, with the slots being sorted according to the production sequence in the line. All parts belong to the same part family that groups several part numbers being similar regarding their function and usage but deviating from each other in form or colour, for instance (Baller et al., 2020). Within the product to be produced, there will never be multiple part numbers of the same part family but exactly one or none (Limère et al., 2012; Zangaro et al., 2021). A possible example for a part family is ‘right front mirror’ encompassing mirrors of different colours. One remark has to be made on the term ‘box’: in order-dependent parts supply strategies it is common to call the boxes ‘(sequence) racks’ or ‘(sequence) wagons’ as the term rack resembles their physical appearance more appropriately, usually being a large box with many dedicated slots (Baller et al., 2020). JIS supply is usually preferred if a high number of part numbers within a part family exist being hard to handle as warehouse parts due to high space occupation. It can also be found under the term externally supplied sequencing in academia (cf. Zangaro et al., 2021).

With **sequencing**, warehouse parts of the same part family are supplied in an order-dependent way from a warehouse to a PSA at the BoL in a sequence rack with dedicated slots being sorted according to the production sequence in the line, each containing the part request for a single production order (Baller et al., 2020; Zangaro et al., 2021). It is also denoted as sequential supply sometimes (Hanson, 2012). Sequencing is quite similar to JIS supply, with the difference that the parts are warehouse parts being picked from an internal warehouse. In industrial practice, this warehouse is usually an intermediate warehouse, denoted as supermarket, containing only the part numbers that are sequenced resulting in reduced picking times compared to larger warehouses. Sequencing is used to save space at the BoL (Sali et al., 2015) and to increase process conformity as the check for the correct part is already made in the supermarket (Hua &

Johnson, 2010). However, it comes at the cost of additional planning and handling steps (Sali et al., 2015).

JIS kit supply is very similar to classical JIS supply: whereas in JIS supply only part numbers of a single part family are supplied, with JIS kit supply kits are supplied. A kit is a 'container which holds a specific assortment of parts' (Bozer & McGinnis, 1992) for one production order. This means that for each production order part requests of different part families are jointly supplied as kits within one rack. Within each slot of the rack, one kit is placed. Of course, a rack can in its extreme form consist of just one slot, encompassing just one kit for one production order. Its additional advantage compared to JIS supply is the joint presentation of multiple different parts to assembly workers saving time during assembly (Hanson, 2012).

With **kitting**, warehouse parts are supplied in an order-dependent way from a warehouse to a PSA at the BoL in the form of a kit encompassing part numbers from different part families (Caputo et al., 2015; Limère et al., 2012). Frequently, multiple kits for different production orders are bundled in a sequence rack, with dedicated slots being sorted according to the production sequence in the line, each containing the kit for a single production order (Bozer & McGinnis, 1992). Yet, in the edge case, there might merely be a single kit. In contrast to Baller et al. (2020), kitting with a single kit and kitting with multiple kits are not treated as separate parts supply strategies. In essence, kitting and sequencing are very similar from a process perspective as the main difference lies in the number of part families considered. Another difference is that only stationary kits are consumed directly at the PSA at the BoL, similar to sequenced parts, whereas travelling kits are consumed at multiple workstations in the assembly line (Sali et al., 2015). In the latter case, the PSA at the BoL is just assigned to the workstation at which the first parts of the travelling kit will be consumed. The logistics process for supplying stationary and travelling kits to the PSA is, nonetheless, identical.

With **batch supply**, warehouse parts are supplied in an order-dependent way from a warehouse to a PSA at the BoL in a box containing only the quantity of a part number that is required for a specified subset of production orders at the line (Johansson, 1991). This subset of production orders is usually derived from the production sequence specifying a certain range of sequence positions for which parts must be supplied. Frequently, not only a single part number is supplied but several batch supplied part numbers are bundled within a rack. Each slot within the rack is dedicated to a single part number and contains the quantity required for the subset of production orders to be supplied. Although this parts supply strategy is widely spread in industrial practice, it is underrepresented in the literature. It is often denoted as batch supply in academia (Hanson, 2012), yet the term portioning appears to be common in industrial practice as well. Sometimes it is incorrectly subsumed under line stocking (for instance by Kilic & Durmusoglu, 2015). This subsumption is incorrect, as (1) batch supply is an order-dependent parts supply strategy, whereas line stocking is independent of production orders, and (2) a batch supply rack might encompass more than a single part number.

Table 1 summarizes the benefits and drawbacks of the different parts supply strategies.

Given the benefits and drawbacks of the different strategies, it is common to use a mixture of various parts supply strategies for different part families to feed an assembly line in industrial practice (Baller et al., 2020; Kilic & Durmusoglu, 2015; Limère et al., 2012). As a consequence, companies cannot rely on a single parts supply strategy alone

Table 1. Benefits and drawbacks of the parts supply strategies.

	Benefits							Drawbacks			
	Direct demand consideration	Simple resupply policies and no additional planning steps	Time savings for the assembly worker	Part conformity is checked prior to assembly	Joint presentation of multiple required parts	Suitable for large parts	Suitable for high number of part numbers within a product family	Intermediate storage	Prone to disruptions (e.g. transportation)	High material handling efforts	Hugh space utilization at the line
JIT supply		X				X			X		X
Line stocking		X						X			X
JIS supply	X		X	X			X		X	X	
Sequencing	X		X	X			X	X		X	
JIS kit supply	X		X	X	X		X		X	X	
Kitting	X		X	X	X		X	X		X	
Batch supply	X			X				X		X	

that needs to be enabled physically and by IT systems – but need to enable multiple different parts supply strategies in parallel. Up till now, academia has focused more on providing decision models for choosing among parts supply strategies (e.g. Hua & Johnson, 2010; Sali et al., 2015) and on the physical process and design on the shop floor (e.g. Bozer & McGinnis, 1992; Brynzér & Johansson, 1995; Sternatz, 2015) but less on the associated planning and modelling challenges for industrial companies that need to enable multiple parts supply strategies from picking order planning to picking execution through planning and execution IT systems. This work's goal is to elaborate on whether and how different parts supply strategies can be modelled jointly, based on their similarities and differences, by providing lessons learned from an example in industrial practice where the challenges of joint modelling have been addressed. Joint modelling is a crucial precondition for setting up a software system in industrial practice that covers multiple parts supply strategies efficiently. If they have similar input–output relations and process steps, joint algorithms can be used in the IT system instead of multiple distinct ones. We have actually implemented a new IT system that is based on this joint modelling: the model presented within this work describes all the picking order planning and picking execution steps that the IT system is carrying out. It needs to be emphasized that we will not describe the IT system's exact architecture, which is, of course, company-specific as it has, for instance, to consider different partner systems from which input data is received. Our focus is more on the description of the single steps that the IT system covers as both research and other companies can gain insights from it.

Therefore, Section 2 discusses the differences and similarities of the single parts supply strategies and whether and to what extent different parts supply strategies can be modelled jointly. Based on the results of Section 2, Section 3 presents how sequencing, kitting and batch supply can be modelled jointly by elaborating on the process steps to be carried out, based on an example from the automotive industry. Section 4 concludes this work and sets the agenda for future research.

2. Similarities and differences between parts supply strategies

Whether parts supply strategies can be jointly modelled depends on their similarities and differences, as depicted in Table 2. It is worth noting that batch supply is split there into batch supply (single), if only a single part number is considered, and batch supply (multiple), if several part numbers are considered. The main distinction criteria are:

- Are the parts **warehouse parts** stored in the manufacturer's warehouse or are they non-warehouse parts directly supplied from the supplier?
- Are the parts fed to the line based on actual **part requests for production orders** or are the parts supplied in fixed quantities independent of the production orders?
- Is a **single part number** fed to the line or are multiple part numbers fed to the line within a box?
- If multiple part numbers are supplied, are they of the same part family or do they belong to **different part families**?
- If there are distinct slots within the box, are those **slots dedicated** to the part requests for a distinct production order or are the slots dedicated to a part number?

Table 2. Differences between parts supply strategies.

	Warehouse parts	Parts supplied directly from suppliers	Order-dependent part requests	Order-independent part requests	Single part number	Multiple part numbers	Parts from single part family	Parts from different part families	No slots used	Part number-dedicated slots	Order-dedicated rack slots
JIT supply		X		X	X		X		X		
Line stocking	X			X	X		X		X		
JIS supply		X	X			X	X				X
Sequencing	X		X			X	X				X
JIS kit supply		X	X			X		X			X
Kitting	X		X			X		X			X
Batch supply (single)	X		X		X		X		X		
Batch supply (multiple)	X		X			X		X		X	

The distinction between warehouse and non-warehouse parts has major implications on the parts supply process concerning transfer of risks, stock booking and transmitting of the part requests. The manufacturer is not responsible for the inventories of non-warehouse parts, which are stored at the supplier's site and inventory responsibility is only passed on to the manufacturer with the physical handover and the transfer of risks. Then the stocks are directly booked to the stocks at the PSA at the BoL. As a consequence, no internal stock booking from the manufacturer's stock in a warehouse is required. In contrast, stocks of warehouse parts have to be booked from the warehouse to the stock at the BoL. Moreover, for non-warehouse parts, created part requests have to be transmitted via an electronic data interface (EDI) from the manufacturer to a supplier who uses own and separate IT systems to plan and execute picking orders, whereas for warehouse parts the created part requests can directly be used to plan and execute picking orders. This can, in principle, be done within the same IT system, allowing a joint modelling for warehouse parts–parts supply strategies. As a consequence, it becomes impossible to jointly model parts supply strategies for warehouse and non-warehouse parts as different IT systems will be used by the manufacturer and its usually multiple suppliers for picking order planning and execution. Therefore, the following discussion will focus on parts supply strategies for warehouse parts.

Part requests can, in general, be created independent of the actual demands for production orders, e.g. using a Kanban principle resupplying boxes, which became empty, or dependent on the production orders considering the actual time at which parts will be assembled (Hanson, 2012).

- If demand is created independent of the production orders, the supply occurs in full boxes. Picking is executed on the level of boxes and not on the level of individual parts (Limère et al., 2012). The source storage bin, from which the box is picked, and the quantity of boxes form the relevant pick information.
- If, however, demand is created in dependence of the production orders, actual part requests need to be determined for each production order. Picking is executed on the level of single parts. Besides the source storage bin, also the quantity of parts to be picked and the destination slot form the main pick information.

Thus, part request generation on box level for line stocking deviates considerably from sequencing, batch supply and kitting on individual parts level regarding the part request creation and the picks to be executed. What further distinguishes line stocking from sequencing and kitting is that merely a single part number is picked and not different part numbers. In case of batch supply, it is possible that only a single part number or multiple ones are picked. Even in the case of a single part number being batch supplied, individual parts are picked in an order-dependent quantity and not boxes with order-independent fixed quantities as for line stocking. In essence, line stocking is a parts supply strategy that significantly deviates from the other parts supply strategies for warehouse parts (Bozer & McGinnis, 1992; Hanson, 2012). A joint modelling might still be feasible, yet the different characteristics of part request determination, picking order creation and picking execution strongly advocate for a separate modelling.

The differences between sequencing, kitting and batch supply are much smaller. The main difference between sequencing and kitting is that for a kit not only one part number of a single part family but several ones from multiple part families form the part requests per production order to be supplied (Hanson, 2012). Yet, they share the same logic in determining the part requests, in the creation and execution of picking orders and the dedication of rack slots to production orders. A remark must be made on an edge case for kitting, if a kitting picking order consists of just one kit supplying one production order. In this case, the sequence of production orders no longer plays a role within a picking order, yet the picking orders themselves are sequenced one after another during picking execution. Batch supply does not deviate from sequencing and kitting in part request determination, but only in the aggregation of picks, which are no longer order-specific but part number-specific. Instead of picking into order-dedicated slots, pickers put the picked parts into part number-dedicated slots. The general process between batch supply, sequencing and kitting is, therefore, similar enough that they can be jointly modelled. How they can be modelled jointly is subject to the upcoming section.

3. Joint modelling of order-dependent parts supply strategies for warehouse parts

The main steps in the joint modelling of sequencing, kitting and batch supply are as follows (1) the determination of the part requests per production order (see Section 3.1), (2) the creation of the picking order that bundles several part requests for production orders and that defines the positions for picking execution (see Section 3.2), (3) scheduling and release of the picking order (see Section 3.3), as well as (4) picking and transportation execution of the picking order (see Section 3.4). All these steps have to be implemented within a picking order planning and execution software system to be successfully applied in industrial practice. The joint modelling of the parts supply strategies allows to use the same software system with the same algorithms for the different parts supply strategies sequencing, kitting and batch supply.

The following assumptions hold for the description of the single process steps, based on the example from the automotive industry:

- Within the automotive industry, mixed-model assembly lines are frequently used. Mixed-model assembly lines are assembly lines on which different models are produced in a non-restricted sequence as these models share enough similarities such that processing on the same line is enabled (Ostermeier, 2020). Hence, production orders have different bill of materials (BOMs), depending on some order characteristics such as model type, the engine type or the position of the steering wheel.
- Parts are supplied from intermediate warehouses, denoted as supermarkets, or from a distinct zone within a central warehouse, where only few part families are stored (Brynzer & Johansson, 1995; Battini et al., 2013; Limère et al., 2012). For simplification purposes, the term supermarket will be used for both possible sources in the following.
- The parts supply relation is defined for the relation between a supermarket as source, at which the parts are stored, and a PSA at the BoL, at which the parts are

supplied and consumed by the associated workstation of the production line. This relation will be denoted as a supply stream. Workstations are commonly called takts in industrial practice (Baller et al., 2020).

- Racks are used to deliver the picked parts. A picking order always relates to exactly one rack by which the parts are delivered to the PSA at the BoL. These racks may physically look very different, but they all have the same general structure, being composed of slots dedicated to production orders for sequencing and kitting or to part numbers for batch supply. In the edge case of single kits, a rack may only consist of a single slot.
- It is also worth mentioning that material movements between different warehouse stages are not elaborated on but that the focus is on supply to the assembly line. The supermarket replenishment is typically done using the line stocking policy (Hanson & Brolin, 2013).

3.1. Part requests determination

In a first step, the part requests for every production order to be supplied via the supply stream need to be determined as these part requests are not given as static inputs in industrial practice. In contrast to an assumption often made in academia (cf. Baller et al., 2020; Zangaro et al., 2021), it is not even given that a certain part number is always supplied to a specific PSA and built in at the associated workstation. A single part number might be stored in different supermarkets as the part number might be assembled at different workstations of the production line depending on the model to be produced in the mixed-model line (Schmid & Limère, 2019). Therefore, it is not sufficient to use a simple selection mechanism that compares the part numbers in the BOM with the part numbers stored in the supermarket, but a more complex mechanism is required. Further reasons for a more complex mechanism include that for parts like screws not the entire quantity in the BOM might be supplied via one supply stream. Hence, rules are required based on which the part requests determination is enhanced.

To determine the part requests, information is required about the production orders with their attributes and their BOM, about the master data of the part numbers as well as about the part numbers stored in the supermarket (Bozer & McGinnis, 1992; Brynzér & Johansson, 1995; Hanson, 2012). The basic idea behind the part requests determination is to select those positions of the BOM for a production order where the part numbers match the ones being stored in the supermarket. A rule engine is suggested that allows to maintain condition-dependent or -independent rules for part requests determination, both on part number and part family level. Maintaining a rule on part family level can significantly reduce the master data maintenance efforts as part families often encompass many part numbers, which then do not need to be maintained one by one. Full maintenance flexibility is given as rules can also be maintained on part number level. It should be noted that the assignment of part numbers to part families is important master data, but that the definition of part families is often not straightforward in industrial practice. Which part numbers belong to a part family is often subject to discussions: should there be a part family ‘mirrors’ or is a further differentiation in ‘left mirrors’ and ‘right mirrors’ required? An indication for the definition of part families is that in sequencing, kitting and batch supply, only one part number of a part family should be selected from the bill of material. Hence, practitioners are advised to define part families as granular as required to always select one or no part for sequencing and batch supply, and just one or no part from a part family for kitting.

Rules can be either unconditioned (e.g. ‘SELECT all positions from the BOM WHERE the part number belongs to part family X’) or they can be conditioned (e.g. ‘SELECT all positions from the BOM WHERE the part number belongs to part family X AND the steering wheel position is left-hand’). By using an SQL-based query language, the maintenance of rules becomes easy and straightforward and facilitates extensions as expressions can be added. For instance, with an extended expression, sub-quantities can be set that are smaller than the quantity in the BOM. During production, these maintained rules are interpreted for every production order planned in, resulting in the determined part requests for the production order within each supply stream. It is common that for some supply streams no parts need to be supplied for a production order.

During part request determination, there are no differences between sequencing, kitting or batch supply, which is visualized in Figure 2. As all of them are order-dependent part supply strategies, the same steps to determine the part requests per production order in a supply stream can be applied.

In academia, this crucial process step is only seldom mentioned as it is assumed that ‘information about the assembly sequence, and consequently about the contents [. . .], is not available until relatively shortly before the assembly takes place’ (Hanson et al., 2015). In industrial practice, information about the parts to be supplied can be derived from the point in time on at which the sequence is planned and a production order defined. This is usually done days in advance of the actual physical launch of the production order in the automotive industry. Once a production order is defined, its part requests will remain the same even if the sequence position of the production order changes to an earlier or later position. Hence, the only prerequisite for the parts request determination is that the underlying production order has been created.

3.2. Picking order creation

The next step is the picking order creation, during which (1) part requests for several production orders are bundled to picking orders and during which (2) the picks and the sequence in which they have to be executed are determined. Within academia, the former is denoted as the batching policy and the latter as the picking policy (Brynzér & Johansson, 1995).

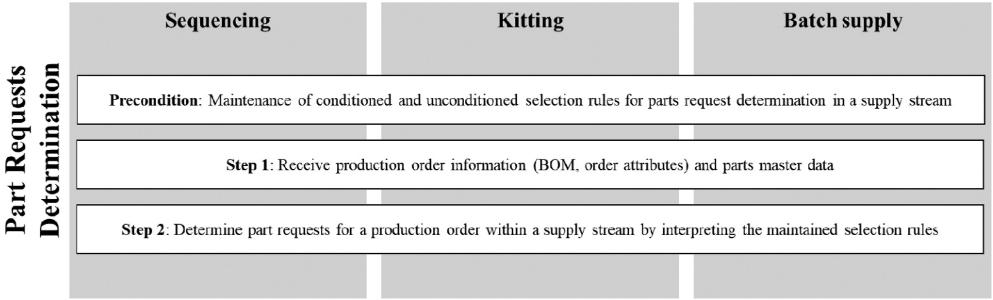


Figure 2. Part requests determination in sequencing, kitting and batch supply.

Before part requests for production orders can be bundled, there must be a logic that releases part requests to be bundled. This release of part requests should ideally happen after the sequence of production orders in the line to be supplied is fixed. A trigger for the release of part requests could be the end of the production sequence planning or the moment when the production order is physically released and enters the production line. Depending on the lead time to supply parts, either the end of a planning step or a physical event can be used as triggers for the release of part requests for bundling into picking orders. If possible, a physical launch would be preferred as a trigger for the part requests release. However, for supply streams supplying PSAs at the beginning of the assembly line, the lead time might be bigger than the time until the production order reaches the workstation supplied by the PSA. In this case, it becomes necessary to use the sequence information from a sequence planning step, although the sequence might still change until the physical launch. Exception handling strategies need to be taken into account such that sequence changes can be handled either within the supermarket or at the assembly line. At the supermarket, non-released picking orders can still be adjusted and the assignment of part request for postponed production orders can be cancelled. At the assembly line, sequence changes have to be communicated to the worker such that he/she knows how to deal with the delivered parts. Delivered parts of production orders postponed in the sequence can be taken out of the rack and placed in temporary buffers from which they will be retrieved later on. Delivered parts of production orders pulled forward in the sequence have to be retrieved from the respective slots in the rack. In this case, the slots in the rack no longer represent the production sequence correctly. Delivered parts of cancelled production orders must be resupplied to the supermarket.

The bundling strategy has to take into account both the utilization of a rack and the adherence to on-time supply (De Koster et al., 2007). On the one hand, part requests for production orders can be added until the rack is full and until every slot is dedicated to a production order in case of sequencing or kitting. For batch supply, part requests can be added until the maximum quantity of a part number in a slot is reached. Thus, the full rack contributes to an optimal utilization of the space at the PSA at the BoL, an enhanced utilization of pickers, and to the minimal number of transports from the supermarket to the PSA (Brynzér & Johansson, 1995). On the other hand, every production order has a different demand time at which its part requests are required at the BoL. Bundling of part requests is, therefore, only possible as long as the difference between demand times for production orders supplied by a picking does not become larger than the replenishment lead time from the supermarket to the PSA.

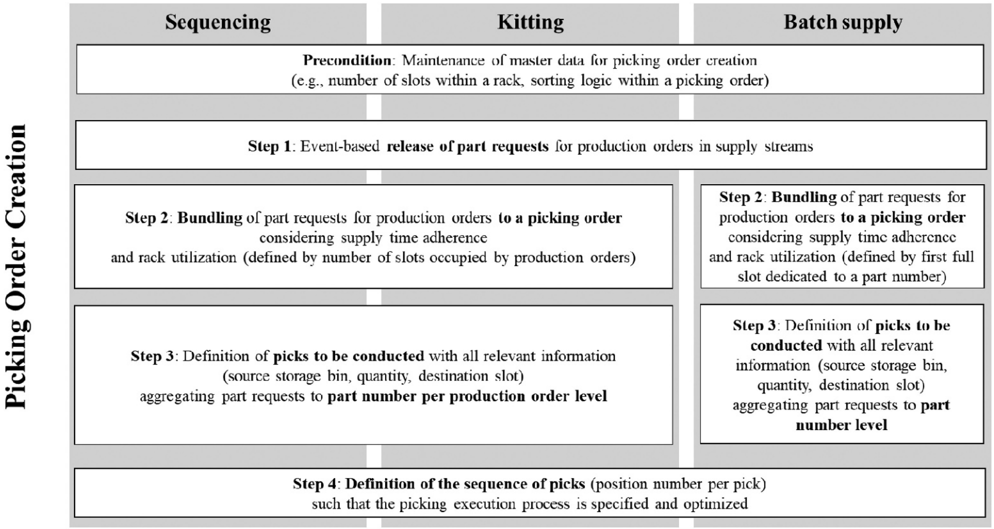
Furthermore, the resulting picking order needs to include all relevant information for picking execution. For every pick a position number is defined, specifying its sequence position during picking execution, as well as the source storage bin, the quantity and the destination slot in the rack as central pick information for sequencing, kitting and batch supply. While for sequencing and kitting part number and production order form the key to a pick, for batch supply the key is the part number only. The difference, hence, lies in the aggregation of part requests to position numbers. Only in case of kitting, the destination slot in a rack may optionally have a formal structure consisting of several subslots, into which different parts have to be put (Hanson, 2012). This subslot would then become an essential pick information as well.

The position number plays an essential role as it affects the efficiency and quality of picking execution. In general, there are multiple ways to execute the picks for sequenced, kitted or batch supplied parts. For instance, in the case of sequencing, a picker could pick the parts in accordance with the destination slots in an ascending manner, i.e. from the first to the last slot, or in a descending manner, i.e. from the last to the first slot. However, this comes at costs of potentially wasted time for walking through the supermarket, which constitutes a substantial fraction of process times during picking execution (De Koster et al., 2007; Hanson et al., 2015). Alternatively, the picker could pick in accordance with the locations of the source storage bins, part number by part number, in a way-optimized manner, starting from either of the two ends of the supermarket, forwards or backwards (Brynzér & Johansson, 1995). These are just a few exemplary logics that result in the assignment of a position number to a pick position. Similar logics exist for kitting and batch supply.

Figure 3 summarizes the main steps for the picking order creation, showing only minor differences between sequencing, kitting and batch supply, which do not interfere with a joint modelling. During step 2, the rack utilization is computed differently for batch supply in contrast to sequencing and kitting. Within step 3, a different aggregation logic is used for batch supply such that picks are aggregated on part number level. Notwithstanding the minor differences, the logic of picking order creation is the same for sequencing, kitting and batch supply.

3.3. Scheduling and release of picking orders

Once a picking order is created, it can be scheduled and released. The general notion behind scheduling of a picking order is to specify times at which the picking order should



Precondition: Maintenance of master data for picking order creation (e.g., number of slots within a rack, sorting logic within a picking order)

Step 1: Event-based **release of part requests** for production orders in supply streams

Step 2: **Bundling** of part requests for production orders **to a picking order** considering supply time adherence and rack utilization (defined by number of slots occupied by production orders)

Step 2: **Bundling** of part requests for production orders **to a picking order** considering supply time adherence and rack utilization (defined by first full slot dedicated to a part number)

Step 3: Definition of **picks to be conducted** with all relevant information (source storage bin, quantity, destination slot) aggregating part requests to **part number per production order level**

Step 3: Definition of **picks to be conducted** with all relevant information (source storage bin, quantity, destination slot) aggregating part requests to **part number level**

Step 4: **Definition of the sequence of picks** (position number per pick) such that the picking execution process is specified and optimized

Figure 3. Picking order creation in sequencing, kitting and batch supply.

enter certain process stages (Schmid & Limère, 2019). A picking order is first released into the backlog of a picker, then goes into picking execution until it is completed and handed over to transportation. When a picking order is handed over, it enters the backlog of transportation. It then goes into transportation execution until the rack is supplied at the PSA at the BoL, where the consumption of the parts takes place.

In its very essence, both the picking and the transportation process can be modelled analogously with a time at which the picking order becomes available for picking or transportation backlog, a start time for the process, a completion time for the process and a buffer after the process. Thus, the following planned times need to be computed to schedule the processing of the picking order:

- planned **release time** as time at which the picking order should be released and becomes part of the backlog of a picker,
- planned **pick start time** as time at which picking of the picking order should start,
- planned **pick end time** as time at which picking of the picking order should be completed and at which the picking order becomes part of the backlog for transportation,
- planned **departure time** as time at which the transport of the picking order from the supermarket to the PSA at the BoL should start,
- planned **supply time** as time at which the transport of the picking order to the PSA should be completed and from which on the parts are buffered at the PSA until they are consumed
- and planned **demand time** as time at which the first part of the picking order will be consumed at the production line.

The computation of the times can be based on various imaginable logics, yet there is an upper bound and a lower bound for each time. The upper bound is formed by the latest timeline that ensures that the picking order is supplied on time, i.e. that the demand time is met, and the production supply is always guaranteed. The lower bound is the earliest timeline taking into account that a rack can only be supplied to the PSA at the BoL, if there is at least one non-occupied storage place. Put in simple terms, the latest timeline defines the 'must' with respect to time adherence, whereas the earliest timeline specifies the first 'can' concerning supply. As a result, there are a latest release time, a latest pick start time, a latest pick end time, a latest departure time and a latest supply time, all being backwards scheduled based on the demand time. Unlike the other times, the demand time is a fixed time given for a picking order. Moreover, there are an earliest pick start time, an earliest pick end time, an earliest departure time and an earliest supply time, all being backwards scheduled from the earliest supply time being computed as the time at which at least one storage place at the PSA becomes unoccupied with a predecessor rack becoming empty. There is no separate earliest release time as this would coincide with the earliest pick start. The earliest pick start is the earliest time at which a picker can start a picking order being equal to the time at which it is released. These boundary timelines are displayed in Figure 4. Within these boundaries optimal pick start times and optimal departure times can be computed considering the utilization of pickers and of transportation. Yet, for many industrial applications it might already be sufficient to compute just the

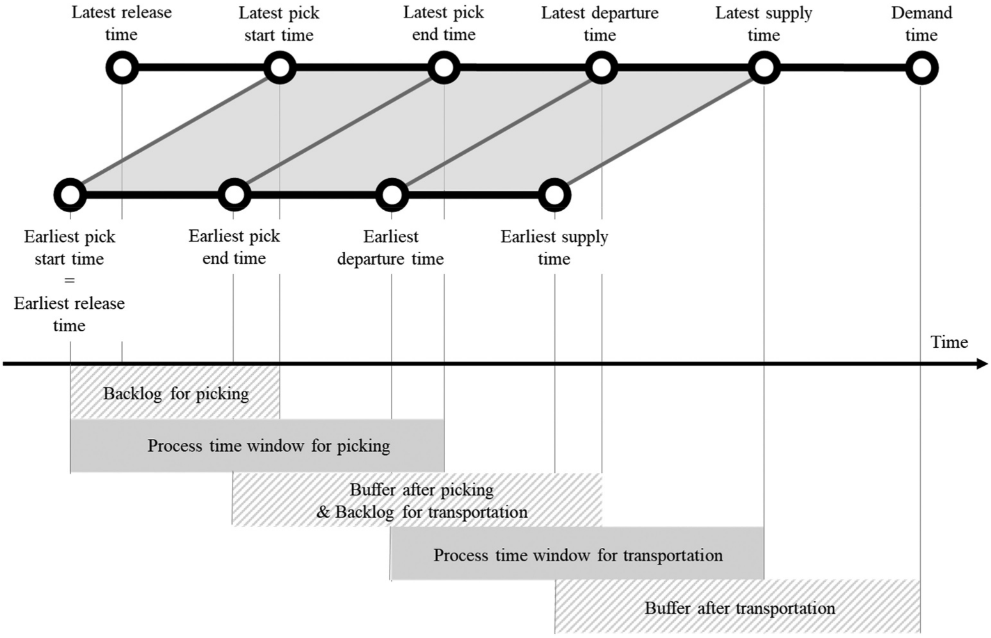


Figure 4. Earliest and latest timeline of a picking order.

boundary timelines giving the pickers and the transportation some degrees of freedom within the execution of picking and transportation. Within academia, the scheduling of picking orders has not received much attention. One of the few works to at least mention backwards scheduling based on the demand time is the one by Schmid and Limère (2019).

The computation of the timelines relies both on static master data such as process durations but also on dynamic input data such as the times at which production orders will consume parts from a PSA at the BoL. Concerning the process durations, the following data must be given:

- **Release lead time** as smallest duration a picking order should be released in advance of its latest pick start,
- **Picking time** as average duration of the picking process for one picking order in a supply stream,
- **Staging time** as average duration a picking order should be buffered between picking and transportation,
- **Transport time** as average transport time from the supermarket to the PSA at the BoL and
- **Safety time** as average buffer time of a rack at the PSA until the first part within the rack is consumed.

Process durations are usually not constant but underly systematic and unsystematic variations. Hence, either average durations or a more complex modelling considering the variations can be used (cf. Ostermeier, 2020).

With regard to the dynamic inputs, a forecasting model is required to determine when a production order will be at a certain point in the production line at which it requires parts to be consumed. This forecasting model can be quite a simple one for paced lines, which operate with a constant speed, whereas it becomes much more complex in the context of unpaced lines where the speed of the line varies. In the case of paced lines, the major input factors are (1) the production sequence (Bozer & McGinnis, 1992), (2) tracking messages from the production orders when they reached certain workstations in the line and (3) the time from one workstation to another in the production line. Based on the tracking information, it can be forecasted when a certain production order will reach downstream workstations by adding up the times from the workstation at which the production order is currently up to the downstream workstation of interest. Using the production sequence, forecasts can be made even for production orders for which no tracking information has been available so far as they, for instance, have not been launched to the production line yet. Please be aware of the fact that the time at which a production order will be at a workstation is also crucial for the first workstations that need to be supplied and for which picking needs to start before the production order is even launched to the production line. In the case of unpaced lines, forecasting becomes more difficult since the time from one workstation to another is no longer a constant and there can usually be buffers between workstations. For forecasting, it is meaningful to use historical data to include a forecast for the times from one workstation to another. Please refer to the vast literature on forecasting part demands in the customer-manufacturer-supplier context (e.g. Gonçalves et al., 2021).

The time at which a production order will be at a workstation forms the demand time for part requests for this production order at a respective PSA being supplied via a supply stream. The demand time of a picking order is the minimum of the demand times of the included part requests at the PSA. Based on this demand time, the single times of the latest timeline can be computed through backwards scheduling. Concerning the earliest timeline, this can again be computed through backwards scheduling based on the earliest supply time being equal to the maximum demand time of the part requests from a previous picking order. After these last parts are consumed, the respective rack is freed up and the storage place at the PSA no longer occupied. The reference picking order is the picking order that has been completed × positions before the current picking order of interest with × being the number of storage places at the PSA. Since the reference points at the time of the earliest timeline, the earliest supply time, and of the latest timeline, the demand time, are computed independently of each other, they may potentially conflict with each other. Such a conflict emerges when the earliest supply time becomes larger than the latest supply time, for example due to high safety times at the BoL. In such a case, the latest timeline is the dominant timeline as it ensures the timely supply. For the earliest timeline, this implies that a rack needs to be supplied to the line although no space is empty yet.

An important remark has to be made on the consideration of working and non-working times within the line and within the supply stream from the supermarkets to the PSA at the BoL. Of course, forecasted times of production orders at workstations can only occur during working times such that non-working times have to be added up whenever a non-working time interval is reached in the forecasting model. During backwards calculation of the planned times from the supermarkets to the PSA, the non-working times have to be added up as well whenever the backwards scheduling reaches a non-working time interval. Moreover, it needs to be emphasized that unexpected disruptions and breakdowns may appear both in logistics and assembly leading to unplanned non-working times. To account for these disruptions, frequent updates of the timelines are required based on the actual heartbeat signals of logistics supply and the assembly line.

After all times have been computed, the picking order can be released. There are multiple possible release strategies such as (1) release always at the earliest pick start making picking orders available to pickers as soon as possible or (2) release when a picking order is full or when the latest release is reached though the picking order is not full yet. Rack utilization and time adherence are two major criteria within the release strategies. Releasing of picking orders is strongly related to the picking order creation, which requires the scheduling of a picking order to be carried out in parallel to the picking order creation. Whenever it is decided to add a new part request for a production order to a picking order, the picking order must be scheduled and a decision on closing the picking order creation and the release has to be made. Moreover, in industrial practice, the number of available sequence racks plays a crucial role and limits the number of picking orders that can be released. There must be at least one empty rack that is not assigned to a picking order being in picking or transportation execution, that is not at the PSA at the BoL nor still in transport back to the supermarket.

Figure 5 displays the major steps to be conducted during scheduling and release of the picking order. There is no difference between the order-dependent parts supply strategies sequencing, kitting and batch supply concerning both scheduling and release as all of them share the same general process steps. Scheduling is only carried out on the level of the entire picking order and does not take into account the single picks or their sequence. The same holds for the release of picking orders.

3.4. Execution of picking orders

When a picking order is released, it becomes part of the backlog of a picker. A picker may be responsible for several supply streams such that he/she must select the next picking

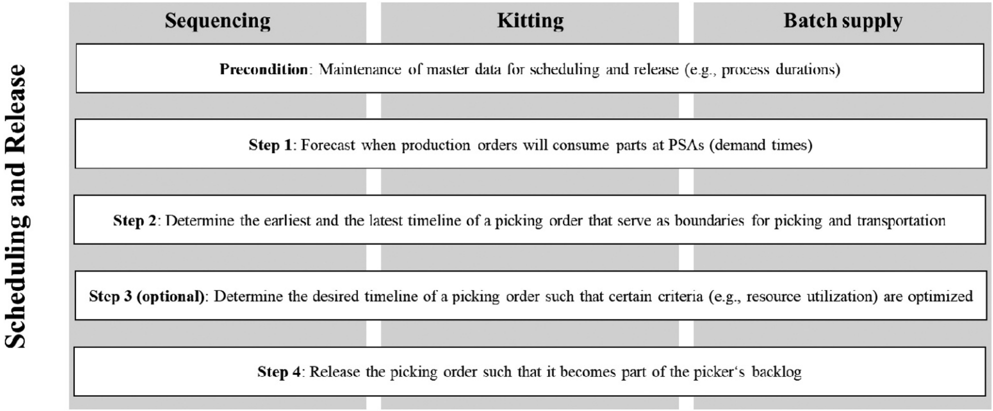


Figure 5. Scheduling and release in sequencing, kitting and batch supply.

order to execute. There may also be multiple pickers within a supply stream such that a decision must be made about which picker takes over which picking order or which part of a picking order (Brynzér & Johansson, 1995; Ho & Lin, 2017). Hence, the first process step of picking execution is the assignment of picking orders, or parts of them, to pickers. This allocation decision may be made by the pickers themselves or by the IT system, following predefined rules and logics. Criteria to be considered include the planned pick start time and the workload of pickers. A classical example is zone picking, where the supermarket is divided into different zones and the picking order is statically divided among those zones (Brynzér & Johansson, 1995). With zoning, pickers could either work in parallel in different zones on the same picking order or in a pick-and-pass fashion successively (De Koster et al., 2007). Static means that the partitioning of picks is independent of the actual context and picks for specific part numbers will always be assigned to a specific picker, whereas a dynamic partitioning would consider contextual factors within the supply of picks (De Koster et al., 2007). Bucket brigade policies dynamically partition the picks as the speed of the individual pickers is taken into account (Koo, 2009). In a bucket brigade, a picker processes a picking order as long as he/she bumps into the downstream picker, to whom the picking order is handed over. When a picker has handed over, he/she walks back upstream until he/she bumps into the upstream picker or the beginning of the supermarket.

The assignment of picking orders to pickers is identical for sequencing, kitting and batch supply. Only in the case of picker collaboration, the partitioning of picks among them considers the different picks for batch supply on part number level and for sequencing and kitting on part number per production order level.

During actual picking, the pickers execute pick position by pick position. Depending on the process configuration, picking from the source storage bin and placing into the destination slot may or may not have to be confirmed through scanning (Hanson et al., 2015). If they have to be confirmed, this can be done for every unit of a part, for a part number for a production order or just for a part number. The latter is common for batch supply, both former for sequencing and kitting. An overview of picking activities to be carried out can be found in Hanson et al. (2015).

An important aspect during picking execution is the way how the picking information is conveyed to the pickers. Instead of classical pick lists (Brynzér & Johansson, 1995), electronic information systems with user interfaces assisting and guiding the picker more and more become the standard. The hardware displaying the picking information ranges from displays over tablets to mobile data entry devices. On these screens, the important pick information (part number, source storage bin, quantity, destination slot) needs to be visualized. Either one pick after another is displayed, given the picker no degree of freedom in the sequence of pick executions, or several picks are displayed on the screen giving the picker several degrees of freedom to self-optimize the picking execution.

The visualization of the picks on screens might be assisted or fully replaced by pick-by -X systems. They simply assist the picker during the picking process by displaying the information or parts of the information not on a screen, but by different means. Such pick-by-x systems encompass particularly the following technologies:

- **Pick-by-light systems**: By means of light signals the next storage bin from which a pick has to be made and/or the destination slot of the pick in the rack is highlighted (Stockinger et al., 2020). Pick-by-light systems are often used in addition to the screens to help the pickers to find the source and destination locations faster. However, they can even fully replace the standard screen that displays the pick information if small electronic displays at the source or destination locations are used. These do not only light up but also display important information as the part number or the quantity. In our implemented IT system, for instance, both assistance and full replacement of screens is enabled.

- **Pick-by-voice systems**: The same statements hold for pick-by-voice systems that convey the pick information to pickers via voice – often either via headphones or via loudspeakers. For each pick, information is given to the picker such that it assists information on a screen or replaces the screen fully. Moreover, pick-by-voice systems can replace confirmation steps via scanning as the confirmation can be done by voice feedback from the picker.
- **Pick-by-motion systems**: Whereas pick-by-light and pick-by-voice systems can replace the screens, pick-by-motion systems only assist the pick information displayed on screens. With pick-by-motion systems, pickers can give motion feedbacks that are recorded by a camera or photoelectric barriers. This can again replace confirmation steps usually done by scanning since the motion is recorded. When a picker withdraws a unit from a storage bin or places a unit into a destination slot, this can be directly confirmed.
- **Pick-by-projection**: Projections can be used to visualize source storage bins or destination slots, either displaying mere light points or information such as the quantity to be picked. Similar to pick-by-light and pick-by-voice systems, they can either assist or replace the pick information display on screens.

This list of pick-by-X systems is far from being complete. You may refer to Baechler et al. (2016) or De Vries et al. (2016) for more information on pick-by-X systems. Yet, it already shows that any of these systems always fulfil the same function: providing further assistance on top of the information on a screen or replacing the information displayed on a screen. The information used is the same such that it is based on the very same planning steps described above. Moreover, there might be further automated devices assisting the picker such as automated guided vehicles that transport the rack and stop at the different locations where a pick has to be conducted. In order to use such external hardware components, which usually have a separate software, information must be provided from the picking execution system via interfaces to these external software systems that steer the hardware components. From our experience, we can give the advice to not integrate such external systems directly into the picking execution system but to simply transmit information from the picking execution IT system to the software system steering these external software components and vice versa. Pick information must be transmitted to the external system, while the external system must transmit feedback back to the picking execution IT system.

After the pickers have completed the last pick position, the entire picking order is completed, and the rack can be handed over to transportation. Transportation can be carried out by tugger trains, forklifts or automated guided vehicles, to name but a few of the options in intralogistics transports within a plant. During transportation, it is no longer of interest whether it was a sequencing, kitting or batch supply picking order, as

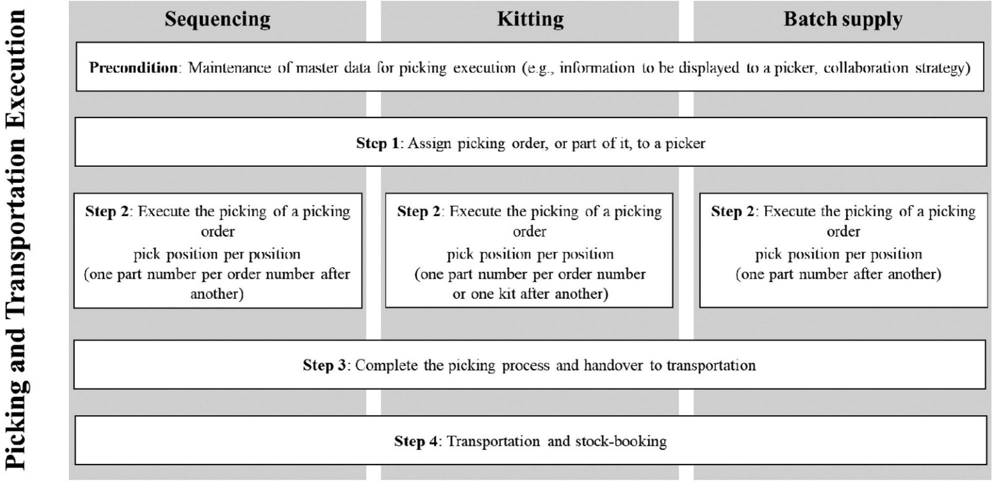


Figure 6. Picking and transportation execution in sequencing, kitting and batch supply.

transportation sees it as a box to be transported from the handover area to the PSA at the BoL within the planned time. Having delivered the box at the PSA at the BoL, the stock movement also has to be booked.

Figure 6 visualizes the main steps during picking and transportation execution, emphasizing that the main difference between the parts supply strategies lies in the actual pick positions to be picked, while also showing the vast similarities. Since transportation is identical for all parts supply strategies and not the focus of this work, transportation is not further elaborated on.

4. Conclusion and future research

This work shared insights on the joint modelling of the parts supply strategies sequencing, kitting and batch supply for warehouse parts with a focus on the process steps to be conducted in picking order planning and execution. The joint modelling serves as a precondition for the implementation of an efficient software system in industrial practice. Part request determination, picking order creation, scheduling, release as well as picking and transportation execution follow the same process steps and can be jointly modelled quite easily. Their main difference lies in the actual picks to be executed, which form no obstacle to joint modelling: one part number per production order after another for sequencing and kitting, or one part number after another for batch supply. Thereby, the same algorithms can be used for all three parts supply strategies, with only slightly different parameterizations. In contrast, line stocking as an alternative parts supply strategy for warehouse parts requires a separate modelling as there are no order-dependent part requests, picking order creation follows different logics, scheduling is not done based on production orders and picking is not on part number level but on box level. The same arguments hold for JIT supply. Hence, they require different input–output relations and different algorithms to be implemented in software systems. The parts supply strategies JIS supply and JIS kit supply for non-warehouse parts may, in general, be modelled jointly as they are based on production orders, have the same required input–output relations and require the same algorithms in IT systems. However, JIS supply and JIS kit supply require data transmissions between different IT systems at the manufacturer's site and the suppliers' sites, forming a major obstacle for joint modelling.

How these obstacles in joint modelling for JIS supply and JIS kit supply can be overcome forms one interesting topic for future research, as it requires integrated planning along the supply chain across different IT systems. Manufacturers and suppliers need to share interfaces during the planning steps from part requests determination up to picking order execution and transportation. Using the same joint model at both companies facilitates the transmission of data between the companies considerably. Nonetheless, in contrast to the warehouse parts–parts supply strategies, the integrated planning of transportation and a possible resequencing step at the manufacturer's site, due to changes in the production sequence, become additional important planning steps. In industrial practice, the necessity for such a joint modelling of the order-dependent parts supply strategies for warehouse parts and non-warehouse parts is prevalent, and we are currently addressing this issue. We even encountered requirements to combine JIS supply and kitting as from a space occupation at the BoL perspective it may be beneficial to add warehouse parts into a JIS rack coming from a supplier within an internal supermarket. Such combined processes can only be enabled if order-dependent parts supply strategies are jointly modelled both for warehouse and non-warehouse parts and across company borders.

Acknowledgments

We want to thank the reviewers for their valuable comments that improved this manuscript.

Disclosure statement

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

ORCID

Frederik Ferid Ostermeier http://orcid.org/0000-0003-3672-0336
Jochen Deuse http://orcid.org/0000-0003-4066-4357

References

Baechler, A., Baechler, L., Autenrieth, S., Kurtz, P., Hoerz, T., Heidenreich, T., & Kruell, G. (2016). A comparative study of an assistance system for manual order picking–called pick-by-projection–with the guiding systems pick-by-paper, pick-by-light and pick-by-display. 49th Hawaii International Conference on System Sciences (HICSS), Koloa, HI, USA. 523–531.

Baller, R., Hage, S., Fontaine, P., & Spinler, S. (2020). The assembly line feeding problem: An extended formulation with multiple line feeding policies and a case study. *International Journal of Production Economics*, *222*, 107489. https://doi.org/10.1016/j.ijpe.2019.09.010

Battini, D., Boysen, N., & Emde, S. (2013). Just-in-time supermarkets for part supply in the automobile industry. *Journal of Management Control*, *24*(2), 209–217. https://doi.org/10.1007/s00187-012-0154-y

Bozer, Y. A., & McGinnis, L. F. (1992). Kitting versus line stocking: A conceptual framework and a descriptive model. *International Journal of Production Economics*, *28*(1), 1–19. https://doi.org/10.1016/0925-5273(92)90109-K

Brynzér, H., & Johansson, M. I. (1995). Design and performance of kitting and order picking systems. *International Journal of Production Economics*, *41*(1–3), 115–125. https://doi.org/10.1016/0925-5273(95)00083-6

Caputo, A. C., Pelagagge, P. M., Salini, P., Faccio, M., & Cohen, Y. (2015). A model for kitting operations planning. *Assembly Automation*, *35*(1), 69–80. https://doi.org/10.1108/AA-02-2014-020

De Koster, R., Le Duc, T., & Roodbergen, K. J. (2007). Design and control of warehouse order picking: A literature review. *European Journal of Operational Research*, *182*(2), 481–501. https://doi.org/10.1016/j.ejor.2006.07.009

De Vries, J., De Koster, R., & Stam, D. (2016). Exploring the role of picker personality in predicting picking performance with pick by voice, pick to light and RF-terminal picking. *International Journal of Production Research*, *54*(8), 2260–2274. https://doi.org/10.1080/00207543.2015.1064184

Gonçalves, J. N., Cortez, P., Carvalho, M. S., & Frazão, N. M. (2021). A multivariate approach for multi-step demand forecasting in assembly industries: Empirical evidence from an automotive supply chain. *Decision Support Systems*, *142*, 113452. https://doi.org/10.1016/j.dss.2020.113452

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

Hanson, R., & Brolin, A. (2013). A comparison of kitting and continuous supply in in-plant materialssupply. *International Journal of Production Research*, *51*(4), 979–992. https://doi.org/10.1080/00207543.2012.657806

Hanson, R., Medbo, L., Johansson, M. I., Faccio, M., & Cohen, Y. (2015). Order batching and time efficiency in kit preparation. *Assembly Automation*, *35*(1), 143–148. https://doi.org/10.1108/AA-05-2014-046

Ho, Y. C., & Lin, J. W. (2017). Improving order-picking performance by converting a sequential zone-picking line into a zone-picking network. *Computers and Industrial Engineering*, *113*, 241–255. https://doi.org/10.1016/j.cie.2017.09.014

Hua, S. Y., & Johnson, D. J. (2010). Research issues on factors influencing the choice of kitting versus line stocking. *International Journal of Production Research*, *48*(3), 779–800. https://doi.org/10.1080/00207540802456802

Johansson, M. I. (1991). Kitting systems for small size parts in manual assembly systems. In M. Pridham (Ed.), *Production research: Approaching the 21st century* (pp. 225–230).

Kilic, H. S., & Durmusoglu, M. B. (2015). *Advances in assembly line parts feeding policies: A literature review*. Assembly Automation.

Koo, P. H. (2009). The use of bucket brigades in zone order picking systems. *OR Spectrum*, *31*(4), 759–774. https://doi.org/10.1007/s00291-008-0131-x

Limère, V., Landeghem, H. V., Goetschalckx, M., Aghezzaf, E. H., & McGinnis, L. F. (2012). Optimising part feeding in the automotive assembly industry: Deciding between kitting and line stocking. *International Journal of Production Research*, *50*(15), 4046–4060. https://doi.org/10.1080/00207543.2011.588625

Limère, V., Van Landeghem, H., & Goetschalckx, M. (2015). *A decision model for kitting and line stocking with variable operator walking distances*. Assembly Automation.

Müllerklein, D., Fontaine, P., & Ostermeier, F. (2022). Integrated consideration of assembly line scheduling and feeding: A new model and case study from the automotive industry. *Computers and Industrial Engineering*, *170*, 108288. https://doi.org/10.1016/j.cie.2022.108288

Ostermeier, F. F. (2020). The impact of human consideration, schedule types and product mix on scheduling objectives for unpaced mixed-model assembly lines. *International Journal of Production Research*, *58*(14), 4386–4405. https://doi.org/10.1080/00207543.2019.1652780

Sali, M., Sahin, E., & Patchong, A. (2015). An empirical assessment of the performances of three line feeding modes used in the automotive sector: Line stocking vs. kitting vs. sequencing. *International Journal of Production Research*, *53*(5), 1439–1459. https://doi.org/10.1080/00207543.2014.944630

Schmid, N. A., & Limère, V. (2019). A classification of tactical assembly line feeding problems. *International Journal of Production Research*, *57*(24), 1–24. https://doi.org/10.1080/00207543.2019.1581957

Sternatz, J. (2015). The joint line balancing and material supply problem. *International Journal of Production Economics*, *159*, 304–318. https://doi.org/10.1016/j.ijpe.2014.07.022

Stockinger, C., Steinebach, T., Petrat, D., Bruns, R., & Zöller, I. (2020). The effect of pick-by-light-systems on situation awareness in order picking activities. *Procedia Manufacturing*, *45*, 96–101. https://doi.org/10.1016/j.promfg.2020.04.078

Zangaro, F., Minner, S., & Battini, D. (2021). A supervised machine learning approach for the optimisation of the assembly line feeding mode selection. *International Journal of Production Research*, *59*(16), 4881–4902. https://doi.org/10.1080/00207543.2020.1851793