FLEXIBLE PRODUCT ALLOCATION IN DISTRIBUTION PROCESSES IN AN APPAREL SUPPLY CHAIN

Bernd Scholz-Reiter, Michael Teucke*, Anne Schweizer, and Mehmet-Emin Özsahin

BIBA – Bremer Institut für Produktion und Logistik GmbH
at the University of Bremen
Hochschulring 20
D-28359 Bremen, Germany
e-mail: {bsr|tck|vir|oez@biba.uni-bremen.de

Abstract: In apparel supply chains retailers often order large numbers of different product variants with only few pieces, increasing stock levels, while product sales times are often short. This article outlines a concept, how decentralized decision-making based on the concept of autonomous control can be used to achieve more flexible allocation of articles to customer orders. The decision making can use simple heuristic rules. Several rules for articles-to-order allocation are discussed in the context of typical apparel order policies. The rules are applied to a case study in form of an Asian-European apparel supply chain. Additionally, the article examines the requirements of flexible articles-to-order allocations on execution of intra-logistic processes within nodes of the case study's distribution network, such as factories, hubs and warehouses. A technical infrastructure based on the use of RFID technologies is proposed for these network nodes.

1. INTRODUCTION

In apparel supply chains production often takes place in low-wage countries, while demand is located in the industrialized world. Supply chains have to bridge large geographic distances, resulting in long lead times. In contrast, retailers request short lead times and high delivery flexibility, while frequently ordering small numbers of garments across a large variety of product variants. These conflicting objectives often result in high uncertainty and complexity, in particular with seasonal order cycles for fashion products (Brun and Castelli 2008).

One approach to deal with complexity of logistic systems is autonomous control of logistics processes. The concept of autonomous control is characterized by decentralized decision-making by logistic objects (Scholz-Reiter et al. 2009). This article aims to describe, how use of this concept may allow more flexible allocation of articles to customer orders within apparel supply chains. Different heuristic rules for articles-to-order allocation, considering matching of order quantities for product variants, are discussed for typical apparel business/delivery models. The rules are applied to a case study in form of an Asian-European apparel supply chain. The supply chain includes production plants in East Asia and distribution centers in Europe, which deliver garments to retailers in Europe and the Middle East.

Additionally, the paper examines the requirements of flexible articles-to-order allocations for execution of packing and distribution processes within nodes of the case study's distribution network, such as logistic hubs and distribution centers. A technical infrastructure based on the use of smart label technologies is proposed and problems relating to use of RFID systems are discussed.

The structure of the article can be outlined as follows: The second section will describe supply chain and inventory management in the apparel industry, focusing on different order and delivery models as well as common problems in apparel logistics. The third section will introduce the case study of an apparel supplier producing in Asia and distributing the products to customers in Europe. The fourth section will describe autonomous control and how this concept may be applied in order to allocate articles to customer orders more flexibly. The fifth section will examine the requirements of flexible articles-to-order allocations for execution of packing and distribution processes within the nodes of the case study's distribution network. For these network nodes a technical infrastructure based on the use of RFID technologies is proposed and problems relating to use of RFID systems across different continents are discussed. The paper closes with a conclusion and an outlook to future research topics.

2. SUPPLY CHAIN AND INVENTORY MANAGEMENT IN THE APPAREL INDUSTRY

The so called textile process chain includes all process steps of the textile and apparel production and distribution process. The main steps of the textile and garments production process are manufacture of fibers (yarns and threads) by the fiber industry, forming of textile surfaces (fabrics) as well as dressing and colorizing of the surfaces by the textile industry, and manufacturing and finishing of ready-to-wear garments by the apparel industry. The last part of the textile chain is formed by garment retailers, who are responsible for commercial distribution, selling the ready garments to end customers. These steps are usually executed in strictly sequential order, as shown in Figure 1, (Hurcks, 1993). This contribution looks at the part of the textile process chain concerned with apparel production and distribution to retailers.

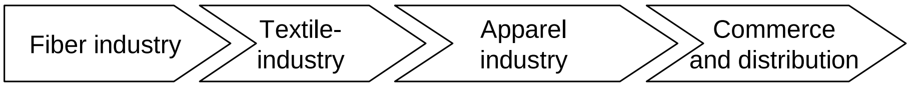

Figure 1. Composition of the textile chain (Hurcks, 1993)

As an important consumer oriented industry, apparel suppliers and retailers have been a driving force to adopt efficient consumer response concepts, like collaborative planning, forecasting and replenishment, or vendor managed inventories (Seifert, 2002, von Heydt, 1999). In reaction to different kinds of products and to the different kinds of retailers and customer requirements, different order and delivery models have been established in apparel supply chains involving retailers and manufacturers or suppliers. The most common order and delivery models are listed in Table 1. Selection of the appropriate model depends on the longevity of the articles' sales periods, which can be grouped into seasonal articles and standard articles sold for many seasons, and according to customer classes. Customer classes can be grouped into small retailers with only one or few sales points, like boutiques or millineries, and large retailers, like clothing chains with many sales points, or mail order wholesalers.

Table 1. Order and delivery models in apparel supply chains (Ahlert and Dieckheuer, 2001, Bruckner and Müller, 2003)

Type of product	Delivery strategy	customer class	
		small retailers	large retailers
Standard products	make-to-stock	• warehouse stock based delivery • never-out-of-stock delivery	• never-out-of-stock delivery
Seasonal articles	make-to-order	• classical seasonal order business	• large retailer orders
Intermediate articles	hybrid forms	• Seasonal Filling Up	• Seasonal Filling Up

As is shown in Table 1, the different order and delivery models can be divided into make-to-stock and make-to-order delivery strategies. Make-to-stock strategies are largely employed for standard articles, which are sold for several seasonal periods without being modified. Warehouse delivery and never-out-of-stock delivery are examples of make-to-stock strategy applications in the apparel industry. Make-to-order strategies are normally employed for more short lived, seasonal products, which are created and sold only for one season and thus follow recent fashion trends. Classical seasonal business and its adapted forms in large retailer business are examples of make-to-order strategy applications in the apparel industry. The most important make-to-stock delivery strategy is never-out-of-stock delivery.

Classical seasonal business is characterized by fixed seasonal cycles with fixed scheduled dates, or phases, for product offers, orders, and delivery, which are repeated twice or four times a year. Assortments of samples, which have been designed by the supplying apparel company for its own brands, are presented to customers by salesmen or at fairs some six to eight months before proposed delivery dates. During a defined order period of roughly three months retailers can order articles in the quantity and variants. Delivery of the products is scheduled by the apparel company at a fixed date or within a fixed time span, starting some three months after the end of the pre-order phase. As production and distribution lead times normally exceed the length of the delivery times expected by customers, production planning and procurement of raw materials have to start before the end of the order periods, using forecasts of the total order sizes based on the orders arrived so far. Products, of which particularly high numbers have been ordered, may be produced in larger quantities and offered again in a second, post-order, phase (Ahlert and Dieckheuer, 2001). As retailers are restricted to ordering a certain quantity of articles from an existing range of products, classical seasonal order is directed largely to small retailers, like millineries or boutiques. For this reason classical seasonal ordering is often characterized by large numbers of orders with relatively small volumes.

For customers, who order large quantities of article items, like clothing chains or mail order wholesalers, the original classical seasonal order business has been adapted to suit their special needs as well as their magnified importance for the supplier's economic success. For this reason, a couple of modifications in dealing with orders of these customers separate them from classical seasonal business. As these customers require specialized products for their own trademarks and, suited to their individual needs product development often is performed as a collaborative process. Ordering and delivery dates are largely dependent on customer wishes as well (Fissahn, 2001).

Most important among make-to-stock delivery strategies is never-out-of-stock delivery, which is a form of vendor managed inventories (Heydt, 1999) employed for non seasonal, long term sold products. Many retailers only hold base stock inventories of these articles, while the suppliers hold inventories to fill them up with short lead times. Retailers review daily (or occasionally weekly) sales volumes in their sales points and reorder these overnight at the suppliers warehouses. Delivery times from the warehouse to the customer are ranging from one to three days. Complete availability (100% service levels) is granted within certain order volume boundaries. Supplier warehouses are refilled periodically from production with a more long termed replenishment process (Ahlert and Dieckheuer, 2001).

Suppliers also occasionally produce articles entirely on their own forecasts, without any pre-orders, and then sell them directly from their warehouses. As long as stocks have not run out, delivery times are comparable to never-out-of-stock delivery. Once warehouse stocks have been used, no reorder possibility for retailers exists (Fissan, 2001).

Several hybrid order and delivery strategies exist, combining different features of the described order and delivery strategies. One example is the so called seasonal filling up products, which combine large retailer orders and warehouse delivery or never-out-of-stock delivery of products during a summer or a winter season. For the next half year, existing retailer stocks are exchanged for the complementary season's products and stored at supplier warehouses, to be delivered again, when the same season arrives again the next year.

Apparel logistics has to cope with a number of specific problems. The most important among these are high product variation, rising stock levels, short product marketing and sales periods, limited demand predictability, and comparatively high product values:

- *High product variation*: Many important retailers have established their own labels and trademarks, for which specific products have to be supplied. These products have to be adapted to the individual requirements of the customer and cannot be supplied to other customers. Additionally, each garment type can be delivered in many different variants, which differ in their colors, sizes and prints. This results in large numbers of brands, fabric qualities, cuts, colors and sizes, which can be combined in various ways. Customers often order small numbers of garments across a large variety of product variants.
- *High and still rising stock levels*: For never-out-of-stock delivery in particular, suppliers often have to keep large inventories in order to be able to react to demand fluctuation faster than with the mentioned, long delivery times. Stock levels in general are still rising due to growing product diversification and variation resulting in rising numbers of products and product variants, to be kept in stock (Scholz-Reiter et al., 2009).
- *Large share of products with short marketing and sales periods*: Many product lines are marked by regular, seasonal exchanges or updates of the product assortment. Once their season has ended, many of these seasonal articles can only be sold with large price reductions or not anymore at all.
- *Volatile demand*: Demand fluctuations are particularly difficult to predict for many short lived, in particular seasonal, products in apparel supply chains due to the effects of fashion tastes. Delivery dates have to be synchronized with anticipated changes between summer and winter collections in stores. The exact dates of the changes however depend on seasonal weather changes, which are difficult to predict during production planning. Retailers, who have to react flexibly to modifications in customer requirements, require from their suppliers the same flexible reaction to demand fluctuation.
- *High product value*: Containers and storage areas filled with garment pieces, represent a comparatively high value for the suppliers.

Retailers additionally have to cope with serious theft rates and relatively high product replacement for end customers unsatisfied with their original buying. These conflicting situations often result in high uncertainty and complexity, in particular for fashion products with short marketing times (Brun and Castelli, 2008, Tellkamp and Quiede, 2005).

As make-to-order products are more challenging in apparel logistics, distribution in classical seasonal business and large retailer order business will be studied in more detail based on a case study of a German apparel supplier.

3. DESCRIPTION OF THE CASE STUDY

The work domain of the supplier is production and distribution of casual and leisure wear. The product assortment includes own brands as well as trademarks of large retailers. For main brands, up to 90 different product types are developed each season. Each garment type can be delivered in different variants, which differ in their colors and sizes; there are e.g. 64 standardized sizes for different countries. Due to the potential combinations of article types, fabric qualities, cuts, colors and sizes the supplier offers several tens of thousands of different article variants.

Altogether, the supplier delivers more than 5 million garment pieces a year of these variants to roughly 6,000 sales points. One half of the sales points belong to large clothing or retail chains, while the other half are small retailers (millineries and boutiques). Most of the customers are situated in central and Western Europe. There is a small, but growing, share of customers situated in Eastern and Northeastern Europe, the Middle East and East Asia.

The supply chain of the case study includes raw material suppliers and a garment production plant situated in southern China, a procurement agency situated at Hong Kong, and distribution centers situated in Europe (Germany). This supply chain is similar to the generic apparel reference supply chain described by Bruckner and Müller (2003).

Production volumes are based on customer orders and own forecasts, as explained in section 2. The orders are sequenced according to required delivery dates and availability of raw materials. Procurement lead times for raw materials are roughly 40 days. Production order throughput times are roughly 10 days from the arrival of the required raw materials. The ready-made garments are transported in standard containers, packed into cartons. A container load consists of 200 to 500 packages of up to 20 pieces each. Packing of packages and containers is product type and variant specific, however not order specific, as order specific picking is restricted to the warehouse. During packing, articles, which have completed production, are counted manually and documented in packing lists, which serve as arrival forecasts for distribution centers.

At the moment product distribution is executed by routing all garments through the distribution center. The distance between Asia and Europe is normally bridged by ship, but in urgent cases air transport may be used. Transports are executed completely by external service providers and are by default routed through logistical hubs, where transport routes and means can be switched. Transport times by container vessel are 30 to 40 days, depending on the route, which is reasonably close to values found in the literature (Pfohl *et. al.*, 2007). Air transport times are only two or three days, but increases transport costs of the same volume and over the same distance by a factor of three to ten compared to transport by container vessel. After arrival at the distribution centre incoming containers are unloaded and packages are put on palettes and stored at free space storing areas until delivery. The packages are counted and compared to dispatch notes, but the articles are only randomly controlled by opening a small sample of the packages. For this reason packing or counting errors at production are often detected only during later picking or even later, by the customer. If stocks of arriving articles in the distribution centre have already run out or have become insufficient, arriving packages will not be put into store, but will be directed to shipping areas of the distribution center, where picking teams can take from them the ordered pieces.

Current process execution with its article being routed through the warehouse results in a number of problems, which are related to the general challenges described in section 2. Arrivals of garments for a product season or a large retailer order cause short, but large peaks in cumulative warehouse stocks and demand large storage areas. After a short time most of these articles have left the warehouse again to be delivered to the customers. However, as the stock based delivery forms are continued independent of these stock level peaks, they need separate storage areas with storage racks for easy picking. For that reason, the areas needed to store seasonal and large customer orders cannot be used for other purposes. This situation results in poor utilization of a significant part of the warehouse storage space.

Picking of orders at the warehouse requires large manual efforts for opening of packages, withdrawal of pieces of the appropriate product variants in the required quantities, and repacking them. This situation results in sharp work load peaks. As timely throughput of large orders is impossible with the warehouse work force, additional workers have to be hired, who are not used to the warehouse processes. This results in poorer efficiency of work processes and higher risk of errors. Routing of garments destined to customers located e.g. in North Eastern Europe or the Middle East through the warehouse results in additional transports and warehouse times and thus in longer product delivery times. Routing through different countries increases efforts for customs handling and product traceability. Difficulties to export garments produced in China to Russia via the European Union may be mentioned as an example.

For these reasons the supplier plans to restructure distribution to direct delivery of the products from factories to part of the customers. Instead of routing all articles through the warehouse, part of the articles should be delivered to customers directly from the factories, while only part of the articles to be delivered is routed through the warehouse, as illustrated in Figure 2. This should result in a more flexible product routing and delivery processes.

Direct delivery however has to cope with a number of challenges due to short term modifications of customer orders. With warehouse based delivery, these are not as serious, as routing of the articles through the warehouse allows reacting to these circumstances, while the articles have arrived there.

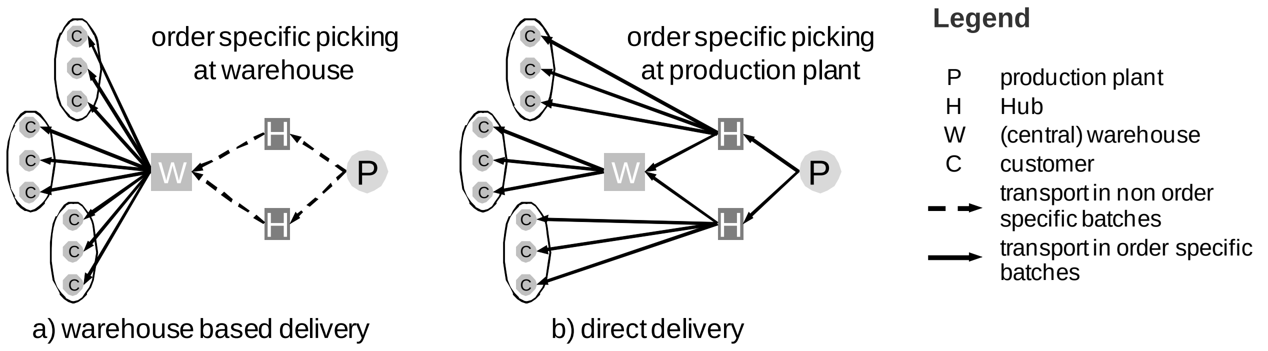

Figure 2. Customer specific article bundling for warehouse based delivery and direct delivery

Customers in classical seasonal business are mainly small millineries and boutiques, which face a high risk of insolvency. Up to some 5% to 10% of the orders have to be kept back, as the ordering customer has become insolvent or is in immediate danger of becoming so. The articles serving such customer orders have to be redirected either to other customers, whose orders are still open, or to the warehouse, where they may be marketed.

Most large retailers however are clothing chains with many, geographically distributed outlets and sales points. Allocation of the cumulated order volumes to the different sales points is often delayed until after the ready-made garments have left factories and are in transport to the distribution center. Allocation may change due to opening of new or takeover of existing outlets, thus increasing overall demand volumes, which require reallocation of articles from existing outlets. Additionally, actually produced article quantities often differ to some degree from ordered quantities, or part of the articles may be damaged or lost during transport. In case of larger differences, more complete reallocations have to be effected between different outlets.

4. AUTONOMOUS CONTROL AND ARTICLE-TO-ORDER ALLOCATIONS

Autonomous control is characterized by processes of decentralized decision making of interacting elements in nondeterministic systems, which possess the capability to render decisions independently. The collaborative research center (CRC) 637, which studies autonomous control at the University of Bremen, postulates that appropriate interaction of the system's elements will improve the performance of a complex logistic system beyond the element's isolated properties; the system will show positive emergence. In particular, application of autonomous control aims to improve a logistic system's response to dynamic instability, caused by sudden changes in the environment, e.g. the market situation, or within the system, e.g. by breakdown of a machine or transport means. This can be summarized by the term increased robustness. (Windt and Hülsmann, 2008).

The elements of such a system are characterized by their ability to process information, to render and to execute decisions on their own. These autonomous, intelligent objects have to be able to collect and process information on their environments and to identify and evaluate alternative process executions, like e.g. alternative transport routes within a logistic network, according to their individual evaluation system. (Böse and Windt, 2007).

Autonomous control is applied to the case study as a simple model, with packaged bundles of article pieces as one kind, and customer orders as a second kind of autonomous logistic objects. Packages will allocate themselves to customer orders based on local interaction between these objects. This allocation then fuels further decisions during the article distribution process, like e.g. selection of the next target nodes for transports of garments within the network, and their transport means, or storage at the factory. As the objects are geographically distributed, the nodes of the supply network will serve as intermediary objects, which collect and disseminate information about the articles and orders. In this way, the allocation can be made for any garment package within the supply network, not only at the final distribution centre. The different types of objects, their roles, objects and tasks are listed in Table 2.

Decisions by the logistic objects have to be based on appropriate decision methods. One potentially viable approach is implementation of rule based decisions (Böse, *et al.* 2005). Such a rule based approach will be followed here.

In a first step, the decision alternatives for each package have to be determined. Potential alternative orders for the allocation of a package can be included into an individual target order set of that package. These alternatives have to satisfy conditions concerning product type and variant (color and size) and delivery dates, compared to current locations and minimum transport times. This order set is gradually reduced during the routing of the articles through the supply network starting with production at the factory, as restrictions become more distinctive and alternatives not meeting these tougher restrictions have to be dropped. In a second step, packages have to select the most appropriate customer order by a package rules for re-allocation of units to orders.

- During production of the garments in the factories the set includes all customer orders, which include articles of the same product type and product variants as those in production. Regional distribution of customers is not important at this stage. This set is uniformly assigned to all garments of the production order. To provide an example, all garments belonging to a production order, which is based on the customer order of a large retailer, will have all sales points of that retailer assigned to them uniformly. No actual allocation of individual garments to customer orders is necessary.
- During packing and dispatch of the ready-made garments packages are allocated to an individual customer order, and filled with garments accordingly. The allocated order is provided the package number and can adjust the number of its “open” articles accordingly. The package’s target order set still includes all customers, who have ordered products of the respective type and variants.
- During transport to a hub and arrival at the hub, due to some dynamic influences as described in section 3, a package may be allocated to another customer order or to no order at all and instead redirected to the warehouse. The package’s target order set includes all customers, who have ordered products of the type and variants and whose products are routed through the respective hub.
- Dispatch of the garments at a hub and transport from the hub to a customer are the last steps, during which the only one finally selected customer order is allocated to each package.

Table 2. Types of autonomous objects in the model and their main properties

objects	**role**	**objectives**	**tasks**
customer order	representation of a customer order	high adherence to delivery dates	• track keeping of the number of “open” garment pieces of each individual article type, for which no articles are yet allocated; • computation of the order priority, based on the importance of the customer; • track keeping of order status;
package	representation of a package with a distinct number of article pieces of certain product variants	short delivery times	• request of orders of articles of their product type and variant (target order set) from hub object; • interaction with orders belonging to target order set request of article allocations; • selection of a customer order to allocate; • selection of the next node in the supply network, and the respective transport means;
supply network hub	representation of hubs in the supply network (factories, logistics hub), information broker	few reallocations, short storage time	• collection and updating of all orders of those customers (sales points), which are served through the respective hub; • identification of packages and their content; • dissemination to package objects of information on orders with articles of their product type and variants; • computation of transport times to other nodes and dissemination of information to packages; • transfer of the resulting packing lists (transport forecasts) to neighboring hubs;

Figure 3 illustrates for a very simple example the mechanism how a package receives information of its target orders from a node object, then interacts with these orders and allocates itself to one of them, based on application of the slack time rule.

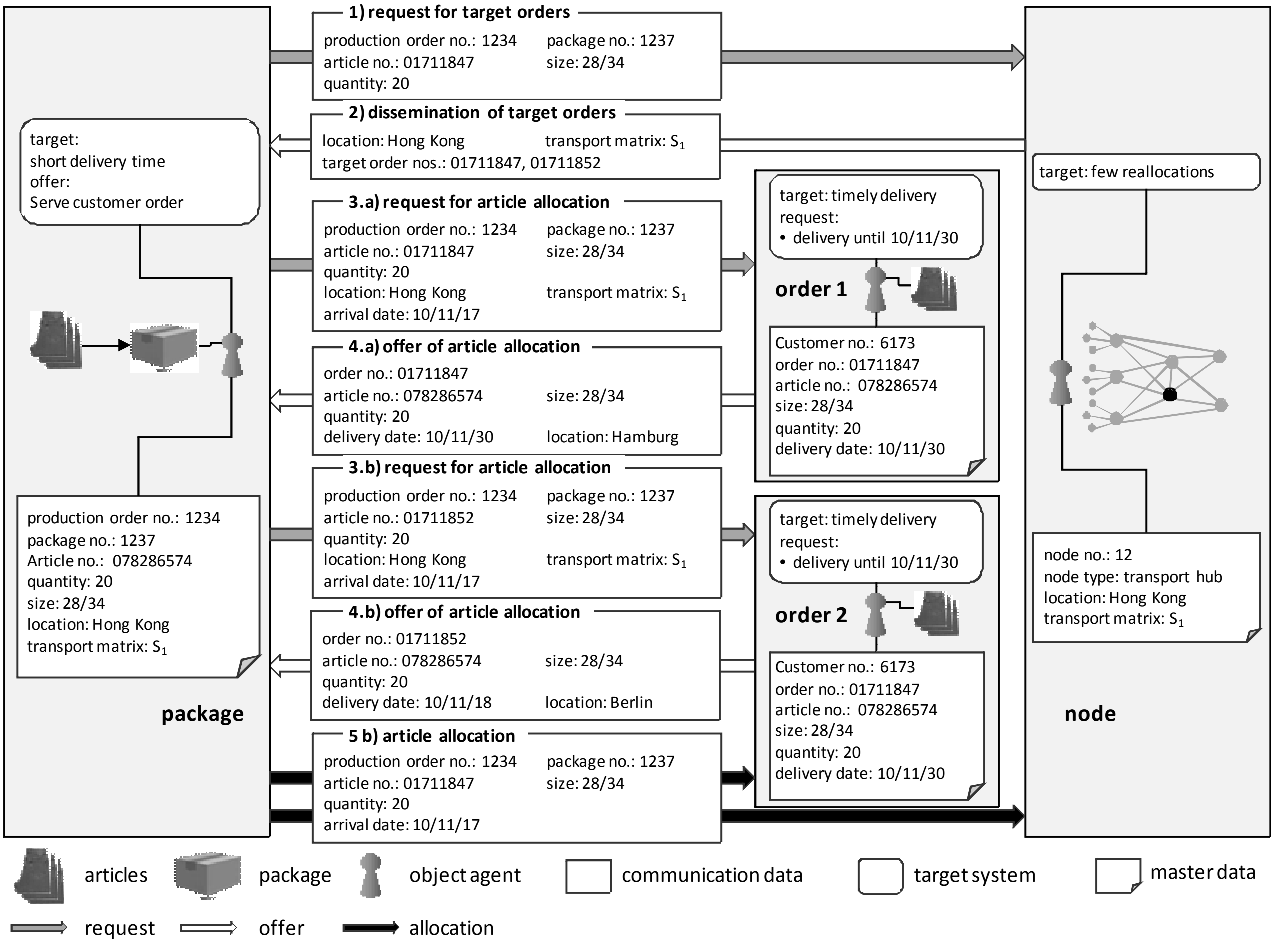

Figure 3. Procedure of package to order allocation based on slack time rule

As mentioned, the actual selection of an order is based on a ranking of all orders of the unit's individual target order set. Based on the requirements of the studied apparel supplier, the following heuristic rules are used to prioritize the customer orders for selection by the packages:

The *shortest servable delivery time* rule is an adaptation of the slack time dispatch rule, which is used for sequencing of production orders in production control (Kistner and Steven, 2001). Packages are allocated to the order with the shortest slack time, which measures the difference between contracted delivery date and anticipated transport times to customer. Slack times until delivery are to be compared to transport times of the articles to the customer. Application of this rule, which is less myopic than alternative dispatch rules, decreases total tardiness for customer orders.

If *customer based order priority* is applied, garments are allocated with priority to those orders of those customers, who are of highest importance for the supplier. Packages with appropriate article variants will be allocated to the highest prioritized order until it is completely served with articles. After that the next highest prioritized order will be served. Customers may be ranked in importance or priority by the supplier according to current or historical overall order volumes, or similar criteria. Application of this rule decreases tardiness for orders by large customers, but may increase tardiness for orders by less important customers. Accordingly, this rule is mainly applied in those cases, when the shortest servable delivery time rule is indifferent to priorities of two different orders.

Generally, differences between ordered and allocated articles have to be minimal over the ordered product variants. The quantities of each product variant is identified in each package and compared to the ordered quantities. Packages are allocated to those orders, where the difference between ordered quantities and physical quantities is minimal over all product variants. Several difference measures can be used, like modulus difference, or quadratic difference, which are summed up for each product variant to arrive at an overall difference.

5. EXECUTION OF PACKING AND DISTRIBUTION PROCESSES

Direct delivery requires individual allotment of ready-made garments to customer orders already at the factories and the hubs. For this reason, articles have to be individually identified at the factories and then tracked during their transport through the supply chain.

RFID technology (Shepard, 2004, Finkenzeller, 2004) offers potential to store individual product related data and additional logistic process data both at item and at unit level, allowing more easily associating correct data to products. This allows better synchronization of physical material flows and associated data flows over supply chains (Gillert and Hansen, 2007, Schuster *et al*., 2007). Application of transponders at item level may be permanent, either by direct integration of transponders into textile surfaces (weaving, sewing or printing), or by application as distinct, permanently applied, but principally removable labels, which are sewed into textiles. For item level applications, a variety of special transponders have been developed (Kallmayer *et al.,* 2003). However, permanent application is still problematic, as life expectancy of transponders added before finishing may be strongly reduced by washing and ironing processes. Permanent labels may reduce wearing comfort of the garments, and acceptance by end customers is not guaranteed.

Alternatively, application may be temporary in form of easily removable labels or stickers. For garments that are stored and transported on hangers, many solutions for transponder integration into hangers have been developed. These are mostly handled sequentially as single pieces in indoor logistics using automated transport systems like conveyors. As this eases automatic identification, barcode and RFID technology for identification are already widely used, often via permanent or removable transponders on the individual garment packaging foils (Schmidt and Mannel, 2002). Storage and transport of garments without hangers, but folded into packages, reduces transponder application on item level. However, it allows application of cheap standard transponders on unit packages like cartons, which reduces the problems relating to transponder technology and application on or in garments, as well as the number of transponders needed to identify the garments.

For application at the case study, combined use of transponders on item and unit levels has been proposed and tested. This allows individual handling of the garment pieces, when needed, as well as limitation to package identification, as long as sufficient. This way, RFID is used to provide the extra-information to allow decentralized decision-making within the supply network’s nodes.

Part a) of Figure 4 shows the transponder labeling and identification process flow at the factory. During the finishing process the ready-made garments are equipped with easily removable transponder labels. The labels can be added as integrated components with the routinely attached size books and price stickers. Based on the Electronic Product Code (EPC) standard, which defines the form and the content of a RFID code, each piece’s information, including article number, size and color information, and an additional serial number of the individual piece is stored into the transponder label. During packing of garment pieces into packages, the pieces can be identified and counted, using either mobile RFID readers or RFID tunnel readers. It is checked that all packages contain the defined number of garments. As packages are equipped in the same way with transponder labels, they can be identified with their included articles as well. The identity of the packages can be allocated to the orders in the order database.

After packing the packages are stuffed into a container, which is used for transport between the production plant and the distribution centers or customers. During container stuffing, the packages are identified and counted using either mobile or gated RFID readers. A packing list of all the packages and articles in the container can be automatically created and sent to the target hub. The packing list can also contain information for customs service procedures.

The intra-logistic processes in a logistic hub are shown in part b) of Figure 4. The processes include warehouse entry, redistribution of packages (as far as necessary), and dispatch. During warehouse entry, an RFID-reader reads the information which is stored on the RFID label belonging to each package. The gathered information is stored in the order database. The actual stock level data of the hub is updated; the order database is compared to the packages receiving simultaneously. If the order has been modified or cancelled during transport, the packages destination will be rearranged to other customers, as described. A similar order can be brought forward for instance. The decisions of rearrangement rest upon information in the order database and application of the allocation rules presented in section 4. If the order is still valid, no rearrangement is necessary. RFID-readers at the warehouse read the information of every leaving package while it is put into a container or trailer.

Part c) of Figure 4 sketches the architecture of a demonstration tool, which realizes the article to order allocations based on the principles outlined in this article. The tool offers interfaces for order entry, RFID based identification of single garments and packages, allocation of packages to orders, and creation of packing lists. Instances of the application can be installed in several network nodes. Next to the main components the tool includes several interfaces to RFID reader infrastructure.

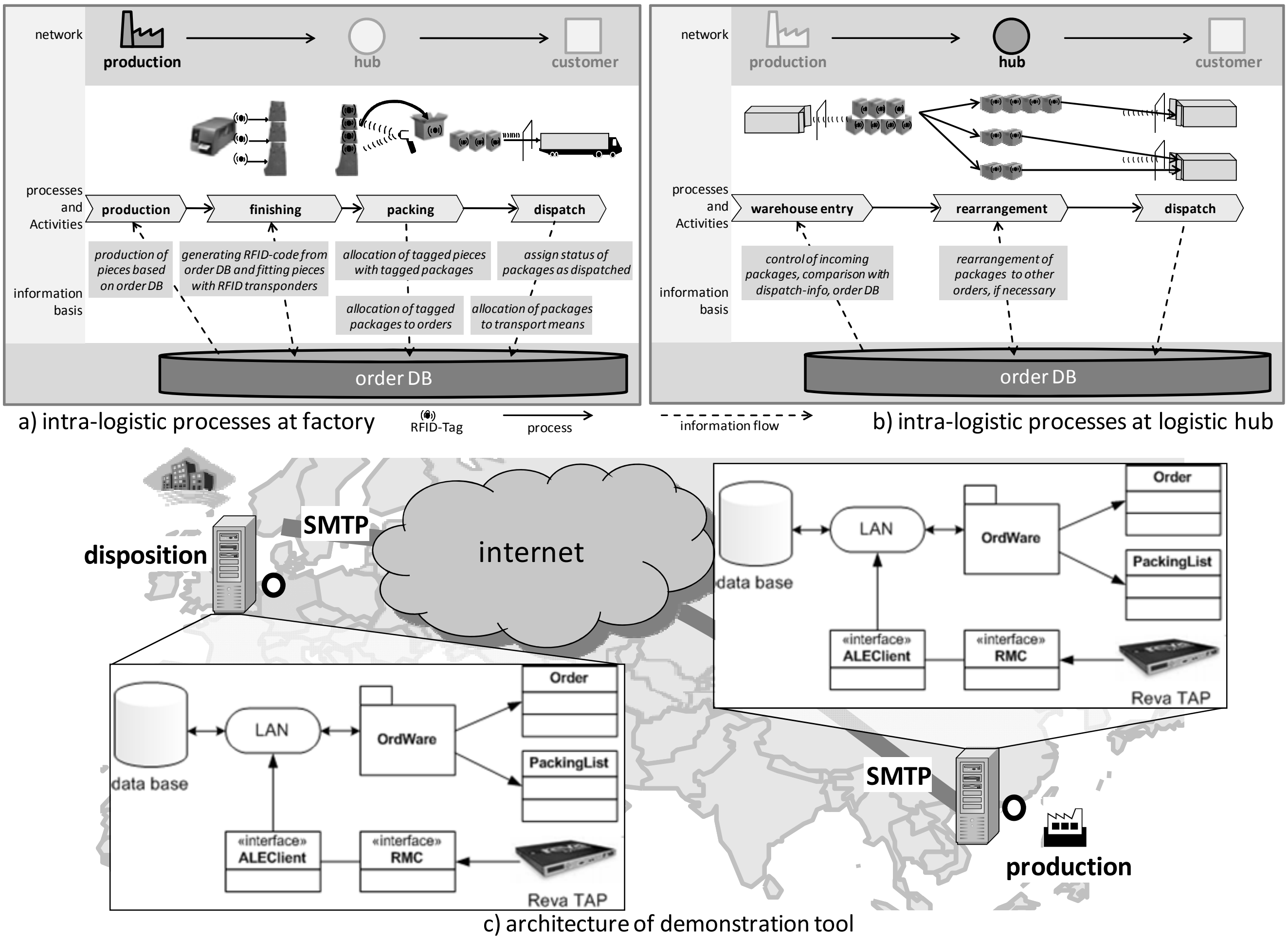

Figure 4. Intra-logistic processes at factory (a) and hub (b); architecture of demonstration tool (c)

6. CONCLUSION AND OUTLOOK

Based on the results of a case study, this paper outlined a concept, how decentralized decision-making based on autonomous control of logistic processes can be used to achieve more flexible allocation of articles to customer orders in apparel supply chains, which have to cope with large numbers of different product variants. Autonomous control can be applied by using packaged bundles of article pieces and customer orders as autonomous logistic objects. Packages will allocate themselves to customer orders based on local interaction between these objects. This allocation then fuels further decisions during the article distribution process, like e.g. selection of the next target nodes for transports of garments within the network or storage at the factory. As the objects are geographically distributed, the nodes of the supply network are used as intermediary objects. In this way, the allocation can be made for any garment packages within the supply network, not only at the final distribution centre. Allocation decisions can be rule based, using combinations of priority rules to rank customer orders, and differences across different product variants. Although the paper deals with a specific case study, results can be adapted to other supply chains adopting similar business models.

Further research is necessary to refine and expand the model of the autonomous logistic objects within transport scenarios and to assign the objects fitting local objectives. The validity of the concept has to be checked by simulations and additional test trials.

ACKNOWLEDGEMENTS

The authors are grateful to the generous support from the German Research Council (DFG) as part of the Collaborative Research Centre 637 “Autonomous Cooperation Logistic Processes – A Paradigm Shift and its Limitations” (CRC637).

7. REFERENCES

Ahlert, D. and Dieckheuer, G. (2001). *Marktorientierte Beschaffung in der Bekleidungsindustrie*. FATM, Münster, Germany.

Böse, F., Piotrowski, J., Windt, K. (2005). Selbststeuerung in der Automobil-Logistik. *IndustrieManagement 20, 4:* 37-40.

Böse, F. and Windt, K. (2007). Catalogue of Criteria for Autonomous Control in Logistics. In: Hülsmann, M. and Windt, K. *Understanding Autonomous Cooperation and Control in Logistics – The Impact on Management, Information and Communication and Material Flow*. Springer, Berlin, Germany, 57-72.

Bruckner, A. and Müller, S. (2003). *Supply Chain Management in der Bekleidungsindustrie*. Forschungsstelle der Bekleidungsindustrie, Cologne, Germany.

Brun, A. and Castelli, C. (2008). Supply chain strategy in the fashion industry: Developing a portfolio model depending on product, retail channel and brand, *Int. J. Production Economics, 116:* 169–181.

Finkenzeller, K. (2004). RFID *Handbook – Fundamentals and Applications in Contactless Smart Cards and Identification*. Carl Hanser Verlag, Munich, Germany.

Fissahn, J. (2001). *Marktorientierte Beschaffung in der Bekleidungsindustrie*. Thesis (PhD). Münster University, Germany.

Gillert, F. and Hansen, W.-R. (2007). *RFID für die Optimierung von Geschäftsprozessen*. Hanser, Munich, Germany.

Heydt, A. von der (1999). Efficient Consumer Response - so einfach und doch so schwer. In: Heydt, A. von der (Ed) *Efficient Consumer Response – Konzepte – Erfahrungen und Herausforderungen*. Franz Vahlen GmbH Munich, Germany, 2–23.

Hurcks, K. (1993): *Internationale Beschaffungsstrategien in der Textil- und Bekleidungsindustrie*. Thesis (PhD). Münster University, Germany.

Kallmayer, C., Pisarek, R., Neudeck, A., Cichos, S., Gimpel, S., Aschenbrenner, R. and Reichlt, H. (2003): New assembly technologies for textile transponder systems. *Proceedings of the IEEE Components, Packaging, and Manufacturing Technology Society: 53rd Electronic Components & Technology Conference*. IEEE Service Center, Piscataway, NJ, USA, 1123-1126.

Kistner, K.-P. and Steven, M. (2001). *Produktionsplanung*. Physica-Verlag, Heidelberg, Germany.

Pfohl, H.-C., Gomm, M. and Shen, X. (2007). China: Textil- und Bekleidungs-Supply Chain zwischen Deutschland und China. In: Wolf-Kluthausen, H. (Ed*). Jahrbuch der Logistik 2007*. free beratung, Korschenbroich, Germany, 258-264.

Schmidt, J. and Mannel, A. (2002). *Einsatzpotenziale der Transpondertechnologie in der Bekleidungsindustrie*. Forschungsgemeinschaft Bekleidungsindustrie, Cologne, Germany.

Scholz-Reiter, B., Teucke, M., Özsahin, M.-E. and Sowade, St. (2009). Smart Label-supported Autonomous Supply Chain Control in the Apparel Industry. *Proceedings of the 5th international Congress on Logistics and SCM Systems*, Program Committee the 5th International Congress on Logistics and SCM Systems, 44-52.

Schuster, E., Allen, S., Brock, D. (2007). *Global RFID: the value of the EPCglobal network for supply chain management*. Springer, Berlin, Germany.

Seifert, D. (2002). *Collaboration Planning Forecasting and Replenishment*. Bonn: Galileo Press.

Shepard, S. (2005). *RFID - Radio Frequency Identification*. The McGraw-Hill Companies, New York.

Tellkamp, C. and Quiede, U. (2005). Einsatz von RFID in der Bekleidungsindustrie – Ergebnisse eines Pilotprojekts von Kaufhof und Gerry Weber. In: Fleisch, E., Mattern, F. (Eds): *Das Internet der Dinge*. Springer, Berlin, Germany, 143-160.

Windt, K. and Hülsmann, M. (2008). *Understanding Autonomous Cooperation and Control in Logistics – The Impact on Management, Information and Communication and Material Flow*. Springer, Berlin, Germany.