AUTONOMOUS ORDER ALLOCATION IN LARGE DISTANCE APPAREL INDUSTRY SUPPLY CHAINS BASED ON USE OF RFID TECHNOLOGY (a case study)

Bernd Scholz-Reiter, Mehmet-Emin Özsahin, Michael Teucke, Afshin Mehrsai

Prof. Dr.-Ing. Bernd Scholz-Reiter is Managing Director of BIBA – Bremer Institut für Produktion und Logistik GmbH at the University of Bremen.
Dipl.-Wirt.-Ing. Mehmet-Emin Özsahin and Dipl.-Wirtsch.-Ing. Michael Teucke work as research scientists at BIBA – Bremer Institut für Produktion und Logistik GmbH at the University of Bremen.
M.Sc. Afshin Mersai is graduate (PhD) student at the International Graduate School for Dynamics in Logistics at the University of Bremen

ABSTRACT

Apparel supply chains have to bridge large geographic distances and cope with low information quality and delayed information flows. Demand oriented disposition is difficult. Transports have to be redirected, or large stocks have to be kept to deal with supply uncertainty.

This contribution describes a control method for refining, autonomous order allocation of goods and articles along the apparel supply chain of a case study. The method allows goods to allocate themselves to customer orders during transport or while being stored, taking into account critical information concerning customer orders and availability of the goods. The allocation can be modified dynamically.

The paper discusses implementation of the method by use of radio frequency identification (RFID) smart labels, which allow storing of individual product related data and additional logistic process data both at item and at unit level and retrieving the data automatically at the location and time of handling.

As shown in simulations, use of the method in apparel supply chains offers improved management of deficiencies, shortages and remaining quantities of goods during the flow of the goods through the supply chain.

INTRODUCTION

The textile process chain combines manufacture of fibres (yarns and threads), forming, dressing and colorizing of textile surfaces (fabrics), manufacturing and finishing of ready-to-wear garments by the apparel industry and commercial distribution to end customers by garment retailers [Hurcks 1993].

Apparel manufacture of the garments has largely been outsourced to low labour cost countries in East Asia and the Middle East [Scholz-Reiter et. al 2008a]. On the demand side future consumer behaviour and demand can be predicted only with difficulty. Retailers require more flexible reaction times and adaptation of suppliers to demand fluctuations. With business models like never-out-of-stock (NOS) delivery garment suppliers take over responsibility for retailer stock levels, while stock keeping by retailers is strongly reduced [Ahlert and Dieckheuer, 2001].

Due to reduced delivery times demanded by retailers and large geographical distances between production facilities and distribution production garment suppliers have to cope with asymmetries between replenishment times demanded by retailers and their own re-supply times from production. Meeting these requirements depends on timely flow of accurate information between production, transport and DC. Apparel supply chains however often suffer from low information quality, delayed information flows and incompatible information and communication systems. Data on the exact number and distribution of articles in production or transport is often inaccurate, and no demand oriented disposition of pieces or transport control is possible. Suppliers are unable to allocate and distribute their articles proactively to urgent customer orders, or to react flexibly to disturbances and demand modifications, while their ordered material is in transport [Bruckner and Müller, 2003].

DESCRIPTION OF THE CASE STUDY

Information quality problems in apparel supply chains will be studied in exemplary form for a jeans trousers supplier, who operates distribution centres situated in three European countries, Germany, Great Britain and Spain. Each of the three DC satisfies local demand for this product, by supplying retailers based on their orders. The retailers sell the garments to end users and replenish their own stocks by daily ordering of articles from the DC. Demand for each product variant varies both seasonally and stochastically.

To replenish the DC, the supplier runs a garment production plant situated in southern China, which is fed by local raw material suppliers. Transport of the finished garments is executed by sea or, in urgent cases, by air. The ready made garments are transported in cartons in folded form. Each carton contains 20 folded garment pieces of the same product variant, colour and size. A carton with its content forms a package. The filled cartons are consolidated into 20 feet containers. One container can transport 200 packages of 20 pieces.

While air transports are directed immediately to airports near the DC, carrier vessels are by default routed via Dubai as a logistical cross-docking hub, where the next transport step immediately follows. This second transport step can again be executed via container vessel or in urgent cases as air transport.

At the distribution centre incoming goods are put into store. Stored articles of the required variants, colours and sizes are picked according to daily retailer orders for each retail store and dispatched to the customers at the same day.

Bad information quality on the availability of goods poses a major problem for stock level control along the supply chain and causes frequent out-of stock situations. Data on dispatched articles is frequently incorrect concerning the actual number of each article type and variant (colour and size) due to incorrect or incomplete counting of wares or incorrect note keeping. As incoming goods are only randomly controlled after arrival at the distribution centre, such errors are frequently not detected nor corrected. This causes discrepancies between the booked and the real number of pieces of articles or article variants available at the DC. If real stock numbers are lower than booked stock numbers, unforeseen out-of-stock situations may occur during picking, so that customer orders cannot be fully served and the order service quality (share of all customer orders that can be served directly) is reduced.

APPLICATION OF AUTONOMOUS CONTROL TO THE CASE STUDY

Autonomous control has been defined as “processes of decentralized decision-making in heterarchical structures. It presumes interacting elements in non-deterministic systems, which possess the capability ... to render decisions independently. The objective of Autonomous Control is the achievement of increased robustness and positive emergence of the total system due to distributed and flexible coping with dynamics and complexity." To summarize the key aspects of autonomous control: "Autonomous control in logistics systems is characterised by the ability of logistic objects to process information, to render and to execute decisions on their own." [Windt and Hülsmann 2008].

In logistic processes, intelligent objects should be able to collect and process information on their environments and to identify and evaluate alternative process executions (e.g. alternative transport routes within a logistic network) according to their individual evaluation system [Böse and Windt 2007].

For the case study, autonomous logistic objects in the model are article pieces, logistic units (which are bundles of article pieces) and customer orders. Individual garment pieces are instances of an article type, which specifies potential customers, quality, colour and size. The integrated smart label based intelligence should enable articles to render and execute their own decisions referring to their own objectives. Two different types of local objectives may be adequate for articles. The first objective should require an article to be sold and delivered to a retailer as soon as possible. The second objective of an article might be to minimize its own transport costs as far as possible.

Articles sharing similar characteristics can be bundled together and form logistic units for storage or transportation. These logistic units should be considered autonomous logistic objects and be provided an identity of their own. Typical bundles are packages and container loads. Additionally, several container loads can be combined to a transport load using the same transport service, i.e. the same ship or aircraft.

Bundling articles into logistic units has to follow predefined rules. A rule may prescribe that only items of exactly the same characteristics may bundle themselves together to form a package (group by product type: e.g. type, quality, and size, colour and production order or production lot). Another rule may prescribe that garment packages may group themselves together to build a transport unit, if they share a common transport destination, (group by destination: e.g. for a distribution centre, or common or similar arrival times at that destination point). Transport loads may split themselves into several new transport loads at each decision point.

Customer orders should be considered autonomous logistic articles, too. A customer order is sent from a customer (retailer) to the garment supplier to initiate delivery of a number of articles. The order specifies a number of garment pieces of one or several article type, to be delivered at a certain delivery date to the customer.

An autonomous allocation of intelligent garments to customer orders and triggering of production orders to prevent out-of-stock situations for a simple two order scenario is illustrated in Figure 1. Part a) shows the inflow of two customer orders to the distribution centre. Order "No. 2" of customer "B" is sent at a later date than order "No. 1" of customer "A". However, it requires an earlier delivery date. The type of the ordered articles is identical for both orders. Part b) shows the dynamic reallocation of articles from their original allocation to order "No. 1" towards the more urgent order "No. 2".

The garments should coordinate their order reallocation behaviour with appropriate messaging and appropriate transport service reselections. If a garment bundle switches its destination order, it has to unsubscribe to the previous order. The switch may initiate additional activities to cope autonomously with the new situation. It may request garments form alternative sources, such as neighbour DC or send a new production order to the production plant, as shown in part b) of Figure 1.

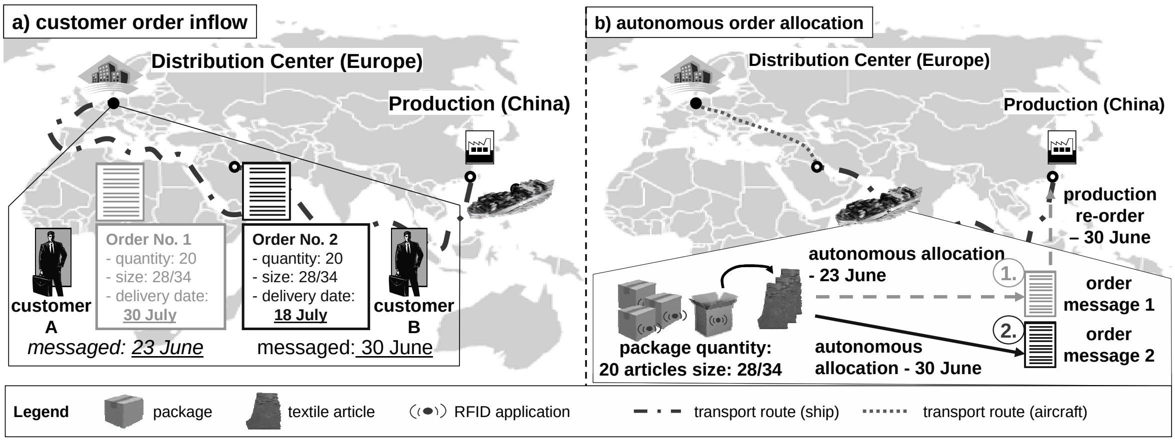

Figure 1 Allocation of autonomous articles to customer orders

Autonomous order allocation should be coupled with dynamic transport route selection by articles. Upon arrival at a decision point autonomous garments should process information whether they will be able to reach their destination in time. If the result is negative, they should separate themselves from the transport and select another transport means or transport route. In Figure 1, part b) the reallocation of the articles from order “No. 1” to order “No. 2” is combined with a change from the original ship transport to air transport at the hub in order to meet the earlier delivery date.
We assume the decisions to be rendered in discrete steps at predefined decision points, where packages should be able to switch their transport destination and their transport means, e.g. from sea carrier transport to air transport. If e.g. a ship transport is delayed, autonomous garments should be able to process this information upon arrival at a decision point in order to find out whether they will still be able to reach their destination in time. If the result is that they will not be able to do so, they should be able to separate themselves from the transport and select another transport means or transport route. In the case study, decision points should be established at each node of the transport network.

USING RFID TECHNOLOGY AS AN ENABLING TECHNOLOGY

RFID technology allows automated identification of physical objects and capture of additional data using radio waves [Finkenzeller 2006]. This allows better synchronization of physical material flows and associated data flows over supply chains [Gillert and Hansen 2007].
The basic RFID application principle for article identification in the case study’s supply chain is based on equipping a removable transponder label to each garment piece during the production finishing process, similar to a size label or a price sticker. The transponder stores article specific information, like article number, size and colour information. Optionally an additional serial number of the individual piece can be used to control individual handling of the article.
Transponders may also be sewed into textiles. For this purpose, a variety of special transponders have been developed by several RFID technology providers [Kallmayer et al 2003]. Application is still problematic in some aspects, however. Life expectancy of transponders added before finishing may be strongly reduced by washing and ironing processes, wearing comfort of the garments may be

reduced and end customer acceptance is not guaranteed. Removable labels however can be applied after the garment production steps have been completed and removed before sale to the end customers.
When combined with other information and communication technologies, RFID technology offers potential for technical realization of autonomous control. Five steps of RFID technology enhancement can be defined to move RFID technology from simple identification of parts via storage of dynamic data, decentralized data processing and communication to intelligent information based material handling allowing autonomous logistic processes [Scholz-Reiter et al. 2008b].
So called pre-processing labels, which are combinations of passive transponders and a micro-processor with limited processing capacity, have been developed [Overmeyer et al 2006]. If it may be assumed that smart labels will become as cheap and ubiquitously available as simple transponders have become today, single garment articles or bundled stock keeping and transport units of garments may be equipped with such labels. These smart labels can form the basis for autonomous control of the garment articles, providing them capabilities to render decisions and to interact with other system elements. Use of enhanced RFID technologies to the case study is described in Table 1.

No.	enhancement	outline of RFID capabilities	application to case study
1	static data storage	storing of data, which does not change over the artefact's life-cycle	article type, size, colour, quality; optionally a serial number for individual pieces
2	dynamic data storage	real time location recording or sensor data recording	current location, current association to a package or transport means
3	decentralized data processing	hostage of software agents [Bussmann et al 2004] on intelligent RFID readers or Personal Digital Assistants (PDA)	allocation of garments to customer order, selection of distribution centre, transport route or transport service
4	interaction between transponders	communication and data Exchange directly between transponders to interact with each other	bundling of garment pieces into logistic units: articles into packages container selection by package
5	intelligent material handling	initiate actions using flexible material handling systems to execute decisions based on information processing	autonomous automatic packing, robot based container stuffing + stripping

Table 1 enhancement of RFID technology for autonomous logistic processes (adapted from [Scholz-Reiter et al 2008b])

A simple solution based only on static data storage, as described in Table 1, step 1, is being implemented now. This solution does not achieve autonomy, but can solve information quality related problems. During packing of garments into cartons the articles are identified and counted using either mobile RFID readers or tunnel readers. All packages can be checked for the number and article variant of the garments inside. Articles are allocated to the carton loads, as cartons are equipped with several transponder labels, too. This provides the necessary redundancy of RFID transponders to deal with RFID reading errors, as the necessary information is stored on both article and package transponders. If one transponder may fail, all information can be reconstructed from reading the other transponders of a package. Weight control can be used for packages, too.

When the packages are stuffed into a container for transport, the packages are identified and allocated to the container load. The resulting packing list is sent to the distribution centre as an avis. It can also serve as an information document for customs procedures. After arrival at the distribution centre, during unloading of the container at the warehouse entry, the cartons are again identified and counted using RFID. The result is compared to the packing list. Identified cartons and the garment articles are added to the warehouse stock data base. If cartons or their contents have suffered from damaging transport conditions, they can be sorted out automatically. During picking and dispatch the individual articles, which have been taken from the storage areas according to the retailer orders, can be checked for conformity to retailer orders to reduce picking errors without costly manual counting.

Capabilities as described in Table 1, steps 2 and 3, add autonomous capabilities to single garments or stock keeping units, as they are essential for data processing by the autonomous units. Capabilities as described in Table 1, steps 4 and 5, are useful additions, but not absolutely necessary preconditions to achieve autonomous control. To achieve an intermediary level of autonomous control, interaction between transponders during bundling may be substituted by fixed rules for packing articles into packages. Execution of decisions intelligent material handling can also be done manually, if the autonomous decisions of intelligent objects are taken into account.

SIMULATION STUDY OF THE AUTONOMOUSLY CONTROLLED SUPPLY NETWORK

To analyze the effects of autonomous control, a simplified variant of autonomous control is simulated and compared to rigid conventional control. A discrete-event simulation approach has been chosen for the experiments.

To reduce complexity the model includes only three different product variants, small sized blue jeans, medium sized blue jeans, and small sized gray jeans. Yearly demand for each variant at each distribution centre is provided in Table 2.

	Germany			United Kingdom			Spain		
Product variant	Blue, short	Blue, medium	Grey, short	Blue, short	Blue, medium	Grey, short	Blue, short	Blue, medium	Grey, short
yearly demand	18,048	9,346	3,460	36,097	18,693	6,921	36,097	18,693	6,921

Table 2 Assumed yearly demand of each distribution centre

The three distribution centers (DC) are modelled as hubs with storage capacity, while the production plant is modelled as a source object, which creates new article pieces. The transport hub at Dubai is modelled as a switch point, alternatively with or without own storage capacity. Each DC and the transport hub represent a decision point, where autonomous articles may redirect themselves to another destination.

The simulated time period is 365 days. Each DC orders for from the production centre to satisfy its own forecast monthly demand. The stock level control cycle period is five days for autonomous systems with monthly demand orders. Replenishment times are set as four months, including production planning, raw material procurement, production and transport. Ship based transport times between production plant and hub are set as 12 days, while aircraft transport is

set as two days. Packages always contain 20 pieces. Containers have a capacity to store 200 packages.
Two methods are compared concerning the service level of customer in the scenario. The first method, conventional control, is characterised by a predefined, fixed transport route and destination and delivery priority. Neither destination nor transport means can be modified according to the real-time demand fluctuations during transport.
The second strategy assumes autonomy for articles, or packages. The products are capable to select their transportation means (either ship or airplane) according to their delivery priority. When the products arrive at the transport hub in Dubai, the transport destination and transport means can be modified regarding the current requirements. During the decision process, the products have to act according to their own given objectives, which regulate them to satisfy the most urgent demand orders.
The two strategies are simulated once with a fixed safety stock coverage of 1000 pieces of each article variant held at the transport hub at Dubai, and once without such a safety stock. The safety stock is assumed to cope with demand level fluctuation and replenishment time.

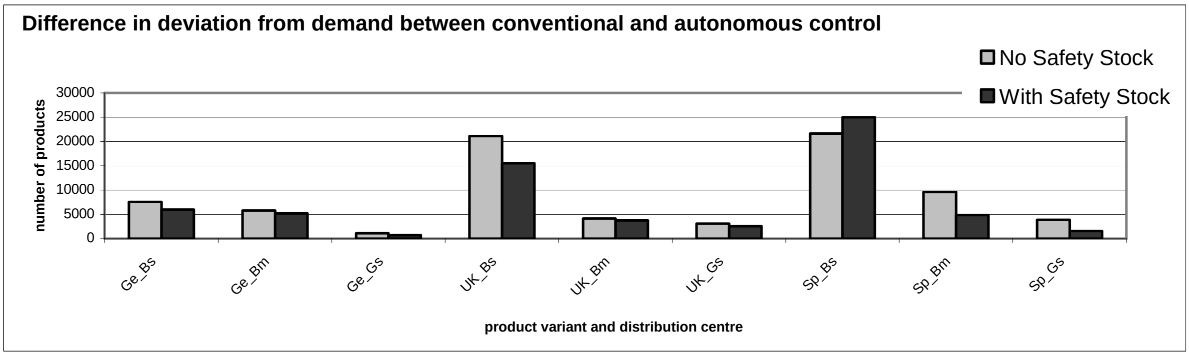

Figure 2 Difference in delivery service levels between conventional and autonomous strategies in terms of their difference values from demands

Figure 2 shows the difference between conventional and autonomous strategies in terms of their delivery deviation from demand. For each product variant and distribution centre two different coloured columns are depicted. The light grey columns show delivery deviation from demand without safety stocks in Dubai, the dark grey columns with safety stock at Dubai. Conventional planning performs worse than autonomous control, as delivery deviations from demands are considerably higher for conventional control for a number of products. In particular, the autonomous system with flexible destination and priority selection according to real-time demand situation meets current demand requirements more often.

CONCLUSION AND OUTLOOK

This paper outlined how problems related to time asymmetries and information gaps in global apparel supply chains relate to a case study of a garment supplier producing articles in China and selling them in Europe.
Coupling of enhanced RFID technology with other information and communication technologies may achieve intelligent objects, which are capable to control their own behaviour in logistic processes. Applications for such

autonomous logistic objects in apparel supply chains are allocation of articles to customer orders and transport route selection. In discrete event simulations, application of autonomous control strategies could reduce delivery deviations from demand and thus out-of-stock situations at distribution centres.

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 more complete simulations, taking into account differences in transport and storage costs.

ACKNOWLEDGEMENT

This research paper is funded by the German Research Foundation (DFG) via the Collaborating Research Centre 637 “Autonomous Logistic Processes – A Paradigm Shift and its Limitations” (SFB 637).

REFERENCES

Ahlert D and Dieckheuer D (2001) “Marktorientierte Beschaffung in der Bekleidungsindustrie”, Münster:FATM.

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. Berlin:Springer, pp. 57-72.

Bruckner A and Müller S (2003) “Supply Chain Management in der Bekleidungsindustrie”, Köln:Forschungsstelle der Bekleidungsindustrie.

Bussmann S, Jennings N and Wooldridge M. (2004) “Multiagent systems for manufacturing control: a design methodology”, Berlin:Springer.

Finkenzeller K (2006) „RFID Handbook“, Chichester:Wiley.

Gillert F and Hansen WR (2007) ”RFID für die Optimierung von Geschäftsprozessen“, München:Hanser.

Hurcks K (1993) „Internationale Beschaffungsstrategien in der Textil- und Bekleidungsindustrie. Thesis (PhD). Münster University.

Kallmayer C, Pisarek R, Neudeck A, Cichos S, Gimpel S, Aschenbrenner R. and Reichlt H (2003) “New assembly technologies for textile transponder systems”, in Howell W and Noctor D Proceedings of the IEEE CPMTS: 53rd Electronic Components & Technology Conference. Piscataway, NJ:IEEE Service Center, pp. 1123-1126.

Overmeyer L, Nyhuis P, Höhn R and Fischer, A (2006) “Controlling in der Intralogistik mit Hilfe von Pre Processing Labels“, in Pfohl H and Wimmer T Wissenschaft und Praxis im Dialog: Steuerung von Logistiksystemen - auf dem Weg zur Selbststeuerung, Hamburg:Dt. Verkehrs-Verlag, pp. 205-215.

Pfohl HC (2000) “Logistiksysteme - betriebswirtschaftliche Grundlagen“, Berlin:Springer.

Scholz-Reiter B, Teucke M and Lo L (2008) „Stellung Chinas in der Bekleidungsindustrie und Auswirkungen auf die Logistik“, in Industriemanagement 24 (1), pp. 15-18.

Scholz-Reiter B, Uckelmann D, Gorldt C., Hinrichs U and Tervo JT (2008) “Moving from RFID to autonomous cooperating logistic processes”, in Miles SB, Sarma SE and Williams JR RFID technology and applications. Cambridge a.o.:Cambridge University Press, pp. 183-197.

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