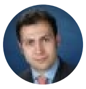
Smart Label-supported Autonomous Supply Chain Control in the Apparel Industry



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Abstract

Classic seasonal order cycles in the apparel industry have been supplemented by Efficient Consumer Response (ECR) driven order policies. Manufacturing often takes place in low-wage countries, whereas demand is located in the industrialized world. The resulting supply chains have to bridge large geographic distances, which reinforce long lead times. In contrast, retailers request short lead times, as forecasting their demand is generally difficult.

Based on a case study of a German supplier of jeans and denim trousers, current information related problems of logistic processes in garment supply chains are analyzed. Solutions are presented to address these problems by use of smart label technologies. In particular, the paper discusses use of smart labels as an enabling technology to implement autonomous control of logistics processes. The concept of autonomous control describes decentralized decision-making in heterarchical structures. The applications of autonomous control, specified in the paper, focus on allocation of garment articles to customer orders and accompanying transport route and transport means selection problems. Although the applications of autonomous control are discussed for a branch specific case study scenario, they can easily be adapted to other enterprises following a similar business model.

Keywords: autonomous control, apparel industry, smart labels, large distance supply chain

1. Introduction

The textile process chain includes all process steps of the textile and apparel production and distribution process. The main steps of the textile and garments manufacturing process are manufacture of fibres (yarns and threads) by the fibre industry, forming, dressing and colorizing of textile surfaces (fabrics) by the textile industry, and manufacturing 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 of the ready garments to end customers. These steps are usually executed in strictly sequential order [5] [8], as shown in Figure 1.

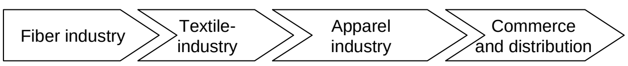

Fig. 1 Composition of the textile chain [8]

Apparel manufacturing processes can be automated only to a limited degree. Manual labour intensity remains high. Up to 80% of the activities are performed manually. For this reason labour costs are the dominant factor in determining total manufacturing costs for garments. On the other hand, due to the prevailing situation of market saturation, prizes remain the most important factor in competition between garment suppliers [5].

For these reasons manufacture of the garments has to a large degree been outsourced to low labour cost countries. While apparel production in industrialized countries, like e.g. the USA or Germany, has decreased to marginal levels, Eastern Asian countries, notably the People's Republic of China, have established large garment industries and have become important exporters of ready made garments to markets in industrialized countries in Asia, America and Europe [7] [8] [14].

European garments suppliers have reduced their own production depths and have taken over responsibility for stock levels of retailer inventories. Thus they have adapted their role towards planning and coordinating activities within apparel supply chains, integrating garment manufacturers and their raw material suppliers, logistic service providers and retailers, while their outbound logistics has to bridge large geographic distances [5].

On the demand side garment retailers and garment suppliers both face the problem that future consumer behaviour and demand vary not only seasonally but also stochastically and can be predicted only with difficulty. Thus, retailers require more flexible reaction times and adaptation of suppliers to demand fluctuations. As a result, garment suppliers have to flexibly modify their own plans and disposition on short notice according to retailer requirements.

Classical seasonal order cycles with fixed start and end dates for design and salesman sample creation, ordering, production and delivery have been supplemented by special contract forms between garment suppliers and large retailers, which grant the latter strong influence in development of individual garment assortments and independence of seasonal order and delivery dates [1].

These business relations often integrate continuous or efficient replenishment concepts, where garment suppliers take over responsibility for retailer stocks, while stock keeping by retailers is strongly reduced [17]. In Never-out-of-stock (NOS) delivery, suppliers continuously replenish retailer stock levels within a few days or even less than a day from local distribution centres, where sufficient stocks have to be kept to guarantee full service levels for specified volumes. Delivery volumes by garment suppliers are rigidly coupled to actual end customer demand.

Suppliers have to provide a high number of different articles and article variants, as retailers often demand specialized designs and cuts, which they can sell exclusively. Each of the designs may be realized varying in colour, accessories, forming, and size.

Due to reduced delivery times demanded by retailers and large distances between geographically widely separated production facilities and distribution centres production planning and logistics of garment suppliers have to cope with asymmetries between replenishment times demanded by retailers and re-supply times of garments from production. In order to cope with these requirements garment suppliers depend on timely and accurate flow of information on the exact type, number and distribution of articles, which are within or leaving production or in transport to the distribution centres [1] [2].

However, apparel supply chains not only have to cope with long lead times, but also 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 and their arrival dates at distribution centres is often inaccurate and therefore generally unreliable. These problems apply in particular to garments, which are transported in folded form and not as garments on hangers. As only unreliable information is available, demand oriented disposition of pieces or transport control is not possible. For this reason suppliers are unable to allocate and distribute their articles proactively to urgent customer orders, or to react flexibly to disturbances caused e.g. by insolvencies of fashion stores, while their ordered material is in transport [2].

2. Case Study of a Garment Supplier

Impacts of information quality problems in apparel supply chains can be demonstrated in exemplary form for a German garment supplier, who is active in production and never-out-of-stock delivery distribution of jeans trousers in several European countries.

2.1 Structure of the Supply Chain

The case study's garment supplier operates distribution centres situated in three European countries, Germany, Great Britain and Spain. Each of the distribution centres satisfies local demand for this product, by supplying retailers. Demand varies seasonally and stochastically regarding the overall size as well as the distribution over these colours and sizes. To replenish the distribution centres, the supplier runs a garment production plant situated in China in the Perl River region, which is fed by local raw material suppliers and coordinated via a procurement agency situated at Hong Kong. Transport of the garments can be arranged by sea or by air.

The disposition office of the garment supplier is responsible for placing replenishment orders of the distribution centres and coordination of the garment supply chain. The geographic locations of the most important parties and the transport routes between them are illustrated in Figure 2.

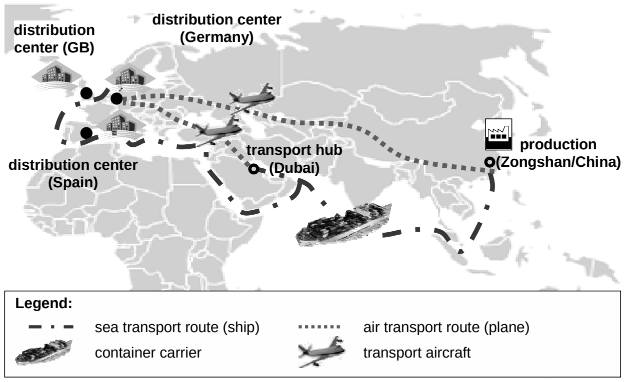

Fig. 2 Transport network of the case study

The roles and activities of the different participating parties within the supply chain can be described as follows:

(1) Local raw material suppliers deliver raw materials (dressed fabrics and additional components like zippers, buttons, and labels) to the production plant.
(2) The production plant manufactures and finishes ready-to-wear garments, and ships the ready-made-garments to distribution centres.
(3) The procurement agency situated at Hong Kong selects the suppliers and orders the raw materials needed for manufacture. This task includes price contracting, book keeping, and quality control.
(4) A local logistic service provider in Asia is responsible for transport of the ready-to-wear garments from production plants to sea or air port.
(5) A global logistic service provider transports garments from the Asian sea or airport to a European sea or airport and additionally further to the distribution centre.
(6) Each of the distribution centres is responsible for distribution of garments to local retailers. Articles sold to end users are replaced and retailer storage inventories are replenished. The procedure includes picking of garments according to daily customer orders and shipping of garments to the customers.
(7) Local logistic service providers in Europe transport the ready-to-wear garments from the distribution centres to retailers by lorry or van.
(8) Retailers in Europe (Germany, Great Britain, Spain) sell the garments to end users; retailer replenish their own stocks by daily ordering of articles from distribution centres in the numbers sold to end customers the previous day.

2.2 Process execution and related problems

The garment supply process includes the process steps production planning, procurement of raw materials, production, transport to the distribution centre, intake and storage at the centre, picking and shipping at distribution centre and transport to the retailer. The garment supplier poses production orders based on fixed order points and fixed order quantities, also called (“s,Q”) rule. If available stocks of an article in the distribution centres fall below a level “s”, a fixed quantity of “Q” pieces of that article is ordered. The values for “s” and “Q” are determined based on average consumption of the past years during the replenishment cycle time (which is by default assumed as five months) and a safety stock coverage, as described in the literature [10].

Based on the production orders and the resulting contract delivery dates the production plant schedules production for a planning period of two months in advance. Production orders are sequenced according to forecasted out-of-stock dates at the distribution centres and according to availability of raw materials.

Raw materials, which include denim or corduroy fabrics and additional components are procured by the procurement agency from local suppliers and delivered directly to the production plant. Garment production in our case study can be divided into fabric cutting, embroidery, sewing and finishing of the garments. Finishing includes washing, thread trimming, buttoning, ironing and labelling. These manufacturing steps are executed in sequential order. Between the steps the garment articles have to pass quality control stations.

As the ready made garments are transported in folded form and not on hangers, the trousers are folded and packed into cartons. Each carton contains 20 folded garment pieces of the same product type and quality, colour and size, which forms together a package. The filled cartons are then consolidated into 20 or 40 feet containers. A container load consists of 200 to 500 packages of 20 pieces of trousers, which are transported in the same container. During packing and shipping, articles, which have completed production, are counted manually and documented in packing lists. The counts are often incorrect or incomplete, resulting in incorrect figures for pieces of articles and their size and colour properties, which causes that the data in the dispatch notes sent to the distribution centres to be incorrect as well.

Intermediary transport between production plant at Guangdong Province (China) and Hong Kong (sea port or air port) is executed by lorry. Between Hong Kong and Europe the garments are usually transported via container vessels, but in urgent cases air transport may be used. While air transports are directed immediately to airports near the distribution centres, container 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. Compared to transport by container vessel, transport of the same volume and over the same distance by aircraft increases transport costs by a factor of ten.

After arrival at the distribution centre the incoming containers are unloaded and the goods are stored. The packages are manually counted and compared to dispatch notes, but the goods are only randomly controlled by opening a part of the packages. The rest of the garments are put into storage directly in unopened packages. The packages are opened only later at picking. For this reason counting errors at dispatch from production are often detected only at picking. If stocks of arriving articles in the distribution centre have already run out or become insufficient, arriving packages will not be put into storage, but will be directed to shipping areas of the distribution centres, where picking teams can take the ordered pieces from them.

At the distribution centre the articles are picked according to retailer orders. Retailers’ replenishment orders are normally based on accounts of their daily sales volumes of the article and are each night transferred via Electronic Data Interchange (EDI) channels to distribution centres. These orders specify for each article the exact number of ordered pieces for each article variant, colour and size. Cumulated order numbers are compared with available article stocks in the distribution centre. If stocks are insufficient for an article or article variant, a non availability message is sent back to the customer. According to the customer orders the ordered article pieces from the available stocks are picked for each house and dispatched to the customers at the same day.

As the process description has shown, bad information quality on the availability of goods of a certain article type and variant (colour and size) poses a major problem for stock level control at different stations along the supply chain, which causes frequent out-of stock situations. Due to incorrect or incomplete counting of wares during packing into cartons or of cartons during container stuffing or due to incorrect note keeping data on dispatched articles are frequently incorrect concerning the actual number of each article type and variant (colour and size). As incoming goods are only randomly controlled upon arrival at the distribution centre, these errors are frequently not detected and thus not corrected. This causes discrepancies between the booked and the real number of pieces of articles or article variants available at the distribution centres. If real stock numbers are lower than booked stock numbers, unforeseen out-of-stock situations or shortages may occur during picking, so that customer orders of that article variant cannot be served and the order service quality (share of all customer orders that can be served directly) is reduced.

3. Technical solution to the case study’s information related problems

For the case study a solution has been developed using radio frequency identification (RFID) technology to solve the specific information related problems. RFID technology allows automated identification of physical objects using radio waves.

Artefacts are equipped with a transponder, which carries a microchip storing data, and an antenna. The antenna transmits the data to a reading device, when triggered by a radio signal of the same device. The reading devices send signals to the transponders to message their data and capture the responses of the transponders. These reading devices are connected to information systems which display or further process the data. Many data carriers can be read simultaneously, while no direct or line-of-sight contact between data carrier and reading device is needed [4].

For these reasons, the technology is widely used to identify objects during production and related logistic processes and to capture the object identity and additional data in a format that is suitable for automated data processing. This allows better synchronization of physical material flows and associated data flows over supply chains [6].

The basic principle of RFID use for article identification during process execution in the case study's supply chain is illustrated in Figure 3:

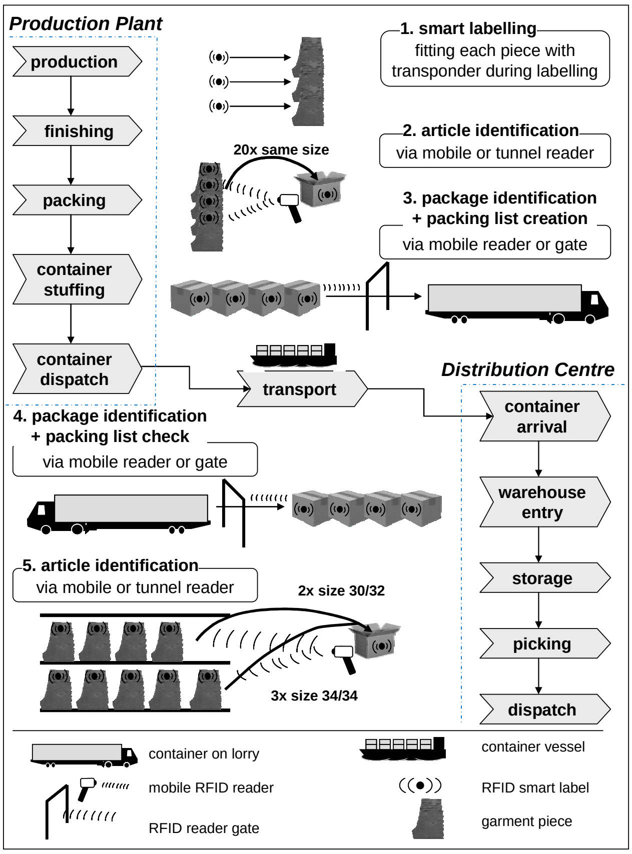

Fig. 3 Use of transponder technology

The steps can be described as follows:

(1) During the finishing process each garment piece is equipped with a temporary, easily removable transponder label. The label is being applied to the article additionally and in parallel to size books and price stickers. Generally, transponders may be applied at item level to individual article pieces and to item individual packing devices or at unit level to bundles of articles, e.g. packing, transport or storage units of articles. Application on several levels may be combined, storing complementary or redundant information. Formatting of transponder data is based on the Electronic Product Code (EPC) industrial standard, using EPC based codes to specify article or transport unit related data [6]. The item transponders store article specific information, such as 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.

(2) During packing of garments into cartons, the articles are identified and counted using either mobile RFID readers or tunnel readers. It is checked that all packages contain the defined number of garments, and that all articles are of the same article variant. Articles are allocated to the carton loads, as cartons are equipped with transponder labels, too.

(3) When the packages are stuffed into a container, which is used for transport between the production plant and distribution centres, the packages are identified and counted using either mobile RFID readers or RFID gates. The packages (and the articles they contain) are allocated to the container load. The resulting, automatically created packing list is sent to the distribution centre and can also serve as information document for customs service procedures, while the container is being shipped and transported to the distribution centre.

(4) During unloading of the container at the warehouse entry, the cartons are again identified and counted using mobile RFID readers or gates. The resulting number of cartons is compared to the number in the packing list, which has been sent as a forecast by the production plant. Identified cartons and the garment articles they contain are added to the warehouse stock data base. If cartons or their contents have suffered from damaging transport conditions, they can be sorted out by an extra reading event, which removes them from the normal stock database.

(5) During picking and dispatching the individual articles, which have been taken from the storage areas according to the retailer orders, can be compared whether they conform to the articles ordered by the retailers in number, type, quality, colour and size. This can reduce picking errors without costly manual counts and checks.

Implementation of these applications can improve data quality for disposition and supply chain control by the garment supplier. In particular, correct application of steps (1) to (3) at the production plant can automate counting of garments, which are shipped to the distribution centres and as a result improve the accuracy of forecast sent by the production plant to the distribution centres. Discrepancies between the booked and the real number of pieces of articles or article variants available at the distribution centres can be significantly reduced. As real stock numbers better conform to booked stock numbers, unforeseen out-of-stock situations or shortages during picking can be reduced and the order service quality be improved.

4. Enhancing RFID systems to enable autonomous control of logistic processes

RFID systems offer potential for added functionality, when they are combined with other information and communication technologies.

Scholz-Reiter et al. [15] define five steps of RFID technology and capability enhancement for moving RFID technology from simple identification of parts via storage of dynamic data, decentralized data processing and communication to intelligent integrated information based material handling allowing autonomous cooperating logistic processes:

(1) In the simplest form, RFID technology may be used for identification of artefacts and for storing static data, which does not change over the artefact's life-cycle.

(2) RFID technology is enhanced by storing dynamic data, e.g. real time location recording using either satellite or terrestrial based positioning systems. Real time location adds flexibility by position tracking of tagged artefacts not only at fixed identification points but at any point within a certain area. Another application of dynamic data processing is integrating sensors and storing sensor data on transponders, e.g. temperature or humidity for shelf life prediction in the food sector.

(3) Decentralized data processing presumes not only storing of data, but processing of data in order to create new data and solve tasks. So called pre-processing labels have been developed, which are combinations of passive transponders and a micro-processor with limited processing capacity [9].
Another to decentralized data processing approach is characterised by usage of software agents, which are hosted on intelligent RFID readers or Personal Digital Assistants (PDA). Software agents are defined as a software structure acting autonomously in some complex environment to realize a set of predefined goals [3]. Agents can be used for e.g. adaptive control of automatically guided transport vehicles [16].

(4) Communication means the capability of transponders to exchange data in order to interact with each other. Today radio frequency is still mostly limited to data exchange between tags and special reading and writing devices. For communicating data to infrastructures beyond RF-enabled systems, other technologies such as wireless Local Area Network, UMTS (Universal Mobile Telecommunications System) or satellite communication are used.

(5) Intelligent information based material handling assumes additional capabilities to intelligent objects, not only to communicate and process information, but also, based on that information processing, to initiate actions using flexible material handling systems [15].

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 and possibility 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." The definition of autonomous control, summarizing the most important aspects is: "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". [18]

In the realm of logistic processes, these intelligent objects will 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.

5. Application of autonomous control to the case study

In chapter 4, step (3), smart labels were introduced as a combination of passive transponders and micro-processors. If it may be assumed that such smart labels will become as cheap and ubiquitously available as simple transponders have become today, even either single or bundled garment articles can be equipped with such smart 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. These enhanced intelligent garments can be used to improve the supply chain, e.g. by dynamic reallocation of the garments in transport to other destinations and customers. This chapter will define a simple structural model of autonomous controlled logistic objects and propose some exemplary applications in the context of the case study.

5.1 Model of the autonomous objects

The modelling framework ALEM (Autonomous Logistics Engineering Methodology) has been developed for modelling autonomous control. The framework is based on the Unified Modelling Language (UML) abstraction model. It is structured by a view concept, uses a set of UML diagrams and some further extensions for notation, and contains a procedure model. ALEM has been implemented in a dedicated modelling tool [12]. The current version of the framework has been developed in context of production logistics. This paper will provide a short description of an ALEM structure model that has been adapted to model autonomous controlled logistic objects in context of the case study. The relevant logistic objects and their relationships are shown in Figure 4 in form of an ALEM structure class diagram.

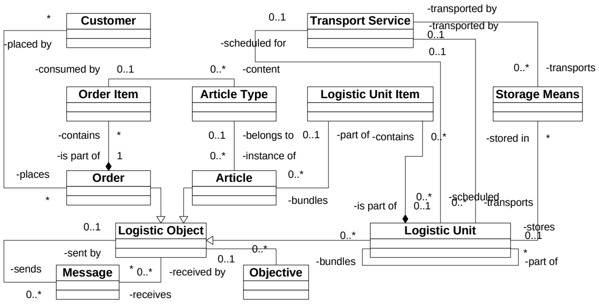

Fig. 4 ALEM supply chain structure diagram

The model is based on the concept of autonomous logistic objects. The objects are characterised by their capabilities to process information and to render decisions on their own, based on their local objectives. They communicate via messages, which they can send to, or receive from, other autonomous logistic objects.

The most important autonomous logistic objects in the model are articles, units of articles and orders. Individual (garment) articles are instances of an article type, which specifies possible customers, quality, colour and size for its instances. The integrated smart label based intelligence enables individual articles to render and execute their own decisions referring to their objectives and destination. Two different types of local objectives may be adequate for articles:

(1) An article might be given the objective to be sold and delivered to a retailer as soon as possible.
(2) The second objective of an article might be to minimize its own transport costs if possible.

A retailer sends a customer order to the garment supplier to initiate delivery of a number of articles. The order specifies a number of articles of one or several article types, to be delivered at a certain date to the customer, who has sent it.

As orders may include articles of different article types, they are composed of several homogeneous order items. Each order item comprises all ordered articles of the same type, same colour and same size.

Articles sharing similar characteristics can be bundled together and form logistic units for storage or transportation. These logistic units can be regarded as autonomous logistic objects themselves. They can be labelled with a smart tag of their own. The tag works as a managing device for the items from the next lower level. It can mediate between the bundled objects and other logistic objects of the same or of a higher level.

Logistic units represent a number of articles, which are related to the same storage or transport means. Logistic units can consist of articles of different article types. Therefore, they are composed of homogeneous logistic unit items. Each bundled item bundles all articles of the same article type within the logistic unit.

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).

Logistic units can be stored in storage devices. Examples of the storage devices are cartons or containers. Article bundles and their storage devices are transported via a transportation service, representing the container vessel’s or aircrafts transportation service to the distribution centre.

As logistic units can combine themselves into larger units, it is possible to model the complete hierarchy in the supply chain:

(-) A package consists of a fixed number of garment pieces of the same product type, colour and size.
(-) Packages can be combined to container load. An average container load consists of 200 to 500 packages.
(-) Several container loads can be combined to a transport load. A transport load combines all articles using the same transport service, i.e. the same ship or aircraft. It has the ability to split itself into several new transport lots at each decision point.

5.2 Application of autonomous control

Intelligent articles or logistic units as autonomous logistic objects should be given the capability to allocate themselves autonomously to existing customer orders and distribution centres. To allocate themselves to a specific customer order, they have to match the requirements of this order concerning number of type, colour and sizes of the article, and they have to be available at the delivery point at the ordered delivery date.

Three situations can be foreseen for garments to modify the allocation to a certain customer dynamically. First, if garments become unable to be delivered to the original selected customer in time due to transport delays and the customer will not accept a delayed delivery, the garments should be able to reallocate themselves to other customer orders with a later, achievable delivery date. Second, incoming emergency orders requiring a very short delivery time should be met by reallocation of articles, which are already in the delivery process for earlier orders with less demanding delivery dates. Third, if customers suffer from insolvency during the delivery process of the ordered garments, the garments should be able to allocate themselves to alternative, still open customer orders, or to initiate marketing and sales measures in order to resell them to other customers. These actions require real time insolvency detection and messaging for each customer.

Figure 5 illustrates the 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. Part a) of the figure 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.

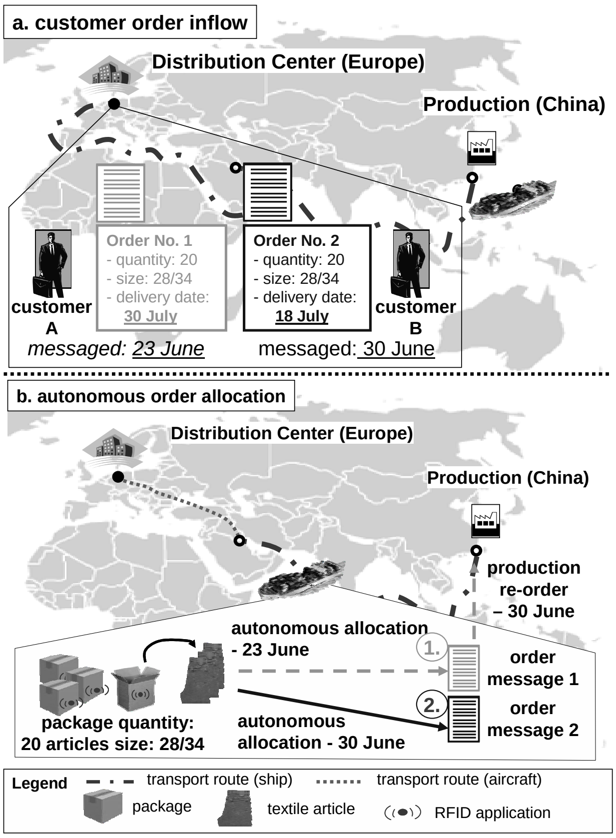

Fig. 5 Allocation of autonomous articles to customer orders

Figure 5, 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 with appropriate transport service reselections. If a garment bundle switches its destination, it has to announce its own transport to the new distribution centre and unsubscribe to the old. The former destination may initiate additional activities to cope autonomously with the new situation. It may request garments form alternative sources, such as neighbour distribution centres or send a new production order to the production plant, as shown in Figure 5, part b).

Application of autonomous objects should enable dynamic selection of the transport route. 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 5, 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.

For dynamic route finding in autonomous logistics systems routing protocols from communication networks have been applied [14]. These protocols specify how the necessary information is exchanged, but they do not include the decision method of the autonomous transport unit or its load.

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. In the case study, decision points should be established at the source point (factory), the transport hub point and the distribution centres.

6. Conclusion and Outlook

This paper outlined problems related to time asymmetries and information gaps in global supply chains in the apparel industry, and how they relate to a case study of a garment supplier producing articles in China and selling them in Europe. RFID technology can be applied to provide a solution to the information related problems identified in the focused case study. The supply chain can be improved by application of transponder labels to articles, by article identification during packing, loading and unloading as well as picking information quality.

Coupling of 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 the described scenario are allocation of articles to customer orders and transport route selection.

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 tested using discrete event simulation to analyse its dynamic behaviour and test of a real life solution.

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