Applying Autonomous Control in Apparel Manufacturing

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Abstract: - Problems caused by manual handling of garments in the apparel industry can be improved by automated data management based on radio frequency identification technology. Autonomous control can be established on top to increase the system robustness and to enable smaller production lot sizes. Different system architectures are defined for autonomous control and technical solutions are proposed to implement autonomous control in apparel manufacturing.

Key-Words: - autonomous control, apparel industry, production planning and control, smart labels, system architecture

1 Introduction

The textile process chain includes manufacturing of fibers by the fiber industry, forming, dressing and colorizing of fabric by the textile industry, manufacturing of ready-to-wear garments by the apparel industry, and distribution to consumers by garment retailers (Fig.1) [1, 2].

Fig.1 Elements of the Textile Process Chain [1].

Up to 80% of the apparel manufacturing processes are performed manually. Labor costs determine total manufacturing costs [2]. For these reasons, garment manufacturing has been shifted to a large degree to low labor cost countries located e.g. in Eastern Asia [1, 3].

In addition, market demand is highly volatile and products exist in many different variants. Seasonal order cycles with fixed dates for ordering, production and delivery are supplemented by contracts that grant large retailers strong influence in development of garment assortments [4]. In never-out-of-stock (NOS) delivery, suppliers are responsible for continuous replenishment of retailer stocks within a few days or less than a day from local distribution centers, where sufficient stocks have to be kept to guarantee full service levels for specified volumes. Delivery volumes are rigidly coupled to actual end customer demand [5].

Conventional approaches for production planning and control (PPC) do not fit properly here [6, 7]. They suffer from unrealistic premises like predictable throughput times, absence of production bottlenecks, fix operation times per order and short machinery downtimes [8]. They owe coupling of PPC processes and tasks, and are not able to map the high complexity of real production systems to a globally consistent model. A dominant central planning top-down approach prevents local problem solutions. Central planning processes do not include company specifics leading to inflexibility and cannot react in real-time to changes in the production system until a new global planning run is made [9].

1.1 Research Question

The apparel industry is situated in the center of the textile process chain. Their manufacturing processes will be investigated exemplary from a case study of a German jeans supplier. Surrounding processes of the supply chain are not in the scope of this article.

Most of the manufacturing and assembly steps are found to be performed manually. Execution of simple tasks is marred by errors, like counting the number of garment articles that have been put into a package. The faulty data are then transmitted to the customer, who is on his part unable to calculate the correct number of garments in travel. Large lot sizes and high lead times add further uncertainness to the textile process chain.

The article aims to identify system elements, processes and structures that are capable to provide consistent information, and to achieve smaller lot sizes and more flexible manufacturing processes in the apparel industry. Automated identification and communication technology and autonomous processes are possible solutions. Their potential capabilities in the application area in apparel manufacturing processes have to be analyzed.

1.2 Paper Outline

The first section introduced the general situation of the apparel industry, pointed out the research questions and outlined the paper's structure. A case study of a German apparel company is provided in the second section. The manufacturing scenario and its problems are described before solutions are proposed. The fourth section introduces autonomous control as a method to cope with the issues noted in the case study. It defines autonomous control in logistics, explains briefly a modeling method for autonomous controlled systems, introduces different system architectures for autonomous control, and applies autonomous control to the manufacturing scenario in the apparel industry. Conclusions and an outlook to future research are given in section five.

2 Case Study and Scenario

Impacts of the problems in apparel manufacturing can be demonstrated exemplarily for a German apparel supplier, specializing in denim garments. The garment supplier operates several distribution centers situated across Europe. Each of them satisfies local demand by supplying retailers in NOS policy. The supplier runs a garment manufacturing plant situated in China in the Perl River region to replenish the distribution centers. The plant is fed by local raw material suppliers and coordinated via a procurement agency situated at Hong Kong. Transport of finished garments is executed by a large logistic service provider either by sea or, in case of urgency, by air.

2.1 Manufacturing Scenario

The garment supply process includes the process steps production planning, procurement of raw materials, manufacturing, transport to the distribution centre, intake and storage as well as and picking and shipping at the distribution centre, and transport to the retailer.

Manufacturing of the garments includes cutting of the fabrics, embroidery (printing), and sewing. Band knifes, manual straight cutters, and auto spreading machines are used for cutting. Over lock, single and double needles, and eyelet machines are used for sewing. Finishing includes washing, thread trimming, buttoning, ironing and labeling. Quality control between the steps includes first checking, size measurement and final checking.

Most work stations at the shop floor are arranged according to the job shop principle. The material flow during manufacture and finishing processes as well as the execution of the manufacturing steps is carried out in sequential order. Half-finished garments are transported between work stations using trolleys. Between and after the production steps, quality gates have to be passed, wherein the trousers are controlled manually.

2.2 Current Problems

The problems faced by this supplier are in particular:

a) The number of pieces delivered to a customer and the distribution of the pieces over different product variants often differs from the number and product variants of articles ordered by that customer.
b) Accounting and book keeping of stock levels for the various products and product variants, is erroneous. Unexpected differences between accounted and real stocks cause sudden stock level run-outs, decreasing delivery service levels.
c) Current manufacturing lot sizes of several hundred pieces and current manufacturing cycles of more than three months are significantly too high.

3 Existing Solutions

Existing solutions can be grouped into organizational, technological or control strategy approaches. This article focuses on technical and organizational solutions with emphasis on auto-identification technologies.

Vertical integration of the value added chain is one strategy of organizational solutions pursued by retailers or garments suppliers [10, 11]. Hereby, independent market players retain their roles but collaborate in joint planning and coordination of their future operations [12].

Highly developed information and communication technology, like auto-identification via radiofrequency (RFID), is available to improve the quality of data acquisition, storage, processing and distribution in processes [13, 14]. It can be enhanced with additional technologies for real-time, dynamic, sensing and mobility purposes, and can be applied in integrated or attached manner at individual article pieces and aggregated units [15, 16, and 17].

4 Application of Autonomous Control in Apparel Industry Manufacturing

The problems described previously can be addressed in two ways. First, the degree of automation can be increased to overcome information problems caused by manual counting of garment pieces. RFID seems to be appropriate here. Second, autonomous control can be established on top to increase the workplaces utilization rate and to enable smaller lot sizes.

4.1 Introducing Autonomous Control

The collaborative research center (CRC) 637 analyzes autonomous control in means of logistics since 2004 and defines it 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 describes the maximum level of autonomous control a system can have, however, specific applications can have a lower level [18, pp.57-72]. In accordance to systems theory this means that abilities are transferred form the total system to its elements [19].

4.2 Development of Autonomous Logistics

Development of autonomous logistics systems requires specification of the system, its simulation and software programming, configuration of the infrastructure that is required for autonomous control in particular, as well as a cost-benefit analysis for economical evaluation [20]. These steps can be performed in cycle to improve the system design iteratively (Fig.2).

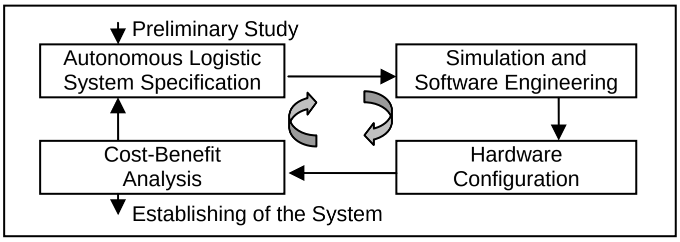

Fig.2 Autonomous Logistic Development Cycle [20].

The modeling framework ALEM, Autonomous Logistics Engineering Methodology, has been developed to specify autonomous logistic systems. It consists of a notation, a procedure model and a software tool [21].

Five views are used to describe specific model aspects. The structure view shows the relevant logistic objects and their relations in a UML class diagram. The knowledge view structures the knowledge, which has to be present at the logistic objects to enable decentralized decision making, by use of knowledge maps. The ability view describes type and structure of abilities that are required by an autonomous logistic object. They can be broken down in sub-abilities, can be interpreted as an abstract set of operations and can be modeled as UML-interfaces. The process view focuses on the logic-temporal sequence of activities and states to describe the flow of material, the progress of processes and the respective control. UML activity diagrams and state machines are employed here. The communication view describes interaction and information exchange between logistic objects in UML sequence diagrams. The message content is modeled in class diagrams. The communication processes are derived from a specific decision method.

4.3 Simulation of Autonomous Control

Simulations have shown that different autonomous decision methods generally work well in manufacturing scenarios even in case of disturbances, like machine break downs. The system can react in a flexible way and can reschedule the commodities waiting in buffers. A standard decision method is queue length estimation (QLE). The autonomous commodity, e.g. a part, forecasts the expected operation lead time to be served at a machine and selects itself the machine associated with the shortest time queue. In a pheromone based approach, information on waiting and processing times of past commodities are collected for each machine and provide the decision base. Following parts select the machines that have achieved the lowest past cycle time. QLE reacts faster and more flexibly then the pheromone concept [22]. Although further research has to adapt these methods to the specifics of the apparel industry, application of autonomous control in the manufacturing process of the apparel industry can be recommended due to similarities in shop floor operations.

4.4 Architectures of Autonomous Control

Potential implementations of autonomous control differ in their degree of autonomy and centralization. They range from completely external control to absolute autonomous control [18, pp.73-83]. The decision for a specific architecture bases upon several criteria, like existing capabilities of the system elements, and on the comparison of costs and benefits of each alternative. Fig.3 contrasts classical PPC-systems to different autonomous architectures described below.

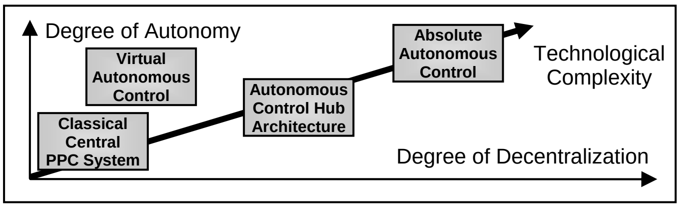

Fig.3 Architectures of Manufacturing Control.

In the *absolute autonomous control architecture*, each object within the system is an autonomous logistic object and is able to render and execute decisions of its own. In a manufacturing scenario there are two different types of system elements that can be employed as autonomous logistic object. On the one hand, there are commodities like finished or half-finished goods, parts, components, raw materials, additives and operating materials. On the other hand, there are elements providing a certain service to commodities, e.g. machines or production centers. Human workers and their workplaces also provide a service to commodities and are put in the same class for this reason. Thus, each sewing machine, workplace and garment component follows its own objectives and has to be equipped with the respective abilities. The system's total complexity will increase strongly and equipping each object with the abilities, e.g. by attaching transceivers and small computers, might be expensive as well.

The *hub-architecture* is located between total autonomous control and centralized, virtual autonomous control architecture. A hub is a system element that follows its own objectives and decision methods, and provides these abilities as service to other logistic objects, too. In this understanding, the hub-architecture establishes a kind of master-slave relation between certain logistic objects. The abilities of decision making and execution are not equally distributed between the logistic objects. Machines and transport devices can be noticed as hubs in a resource centric hub-architecture in manufacturing. Commodities act as hubs, if they offer certain abilities to other logistic objects. This commodity centric approach can be the choice, if commodities share equal characteristics in type, order, date of delivery or lot size, and if only a few of them are equipped with the required abilities to render and execute decisions. The hub-architecture offers several advantages. First, in a manufacturing scenario in which computer numerically controlled (CNC) machines are present, these machines already contain computers as well as common computer and network interfaces. Both can be used for decision rendering and communication with other objects. Second, commodities do not have to be equipped with complex expensive smart tags. They must only be able to store and transmit their objectives and the desired decision method to a hub, and they must be able to receive, store and execute the result from a hub. Even if CNC-machines are not available in apparel manufacture in general, the hub-architecture offers the advantages of autonomous control while the effort for smart tags is low. Hubs can be implemented at each work station to control the manufacturing process of the garments.

Virtual autonomous control is the third system architecture for employing autonomous control in manufacturing. The ability to render decisions is delegated to a central, real-time operating computer system. Each logistic object is represented in this system by an autonomous agent that follows its own objectives and employs its own decision methods. The resulting decisions of each agent are messaged to the respective logistic objects for execution. Decisions are made autonomously within a central system, but are executed in a decentralized manner. This system architecture does not differ strongly from current PPC-systems. For this reason implementation of virtual autonomous control is assumed to be much easier than in the two cases described previously. Nevertheless, each real logistic object has to be equipped with decision execution, transceiver and storage capabilities.

4.5 Autonomous Control in Apparel Industry

Communication and identification technology, as well as self state awareness are the main enabling technologies for employment of autonomous control. Each of them can be realized in a different way. Selection of the identification system is discussed in more detail, because reliable identification of logistic objects solves the information deficit of the downstream supply chain and is important to establish autonomous processes [23].

For application in apparel manufacturing, we propose a system consisting of the logistic objects types orders, half-finished parts, and commodities, which are routed through the factory. Further, intelligent trolleys are used for transportation between machines or manual work stations to perform the manufacturing steps.

Identification can be provided in different stages of the manufacturing process, but the required efforts will vary as well as the availability of certain smart tags might be insufficient. The selection of an identification technology depends on the benefits and challenges associated with each method.

First, smart tags can be included in high density into fabric fibers during fiber or fabric production (Fig.4). Each cut out part is tagged at least once. It is identifiable from the point it has been programmed with a unique ID. Programming takes place right after the part has been cut out of the fabric by passing an RFID gate that is positioned next to the cutting station. The RFID gate is equipped with a communication interface to obtain required data from other system elements, e.g. a PPC system. Alternatively, the RFID gate can be integrated in a trolley. In this case, the tags are programmed when the fresh cut parts are put inside. This procedure improves the production process control, but consumers might decline these products for privacy concerns. Availability of the required very small smart tags is doubtful and radio range is assumed to be low [16, 24].

Fig.4 Autonomous PPC – Intelligent Fiber.

Second, tags can be printed or adhesively bonded to each part before cut out (Fig.5) or right after cut out. The parts are identifiable after being programmed by an RFID gate, as described before. It can prove to be difficult to bond the fabric with tags before cutting parts out, because usually several layers of the fabric are stacked before cut at once. Cutting single layers of fabric is economically inefficient. A special machine is required to bond the smart tags on the fabric when it is rolled out, or alternatively a stamping machine has to be used after cutting to bond the tag at one part after another. Further problems might arise during successive operations, because durability of the bonding ties has to be ensured during manufacturing, whereas consumers probably want to wear tag free garments.

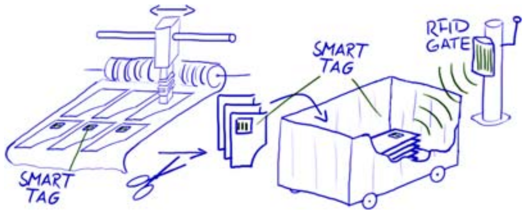

Fig.5 Autonomous PPC – Intelligent Parts.

Third, the ready made garment can be tagged with smart labels when the garment's label is supplied at the last product quality check (Fig.6). The smart tags can be included in the paper labels of jeans garments and can be programmed by an RFID gate. No acceptance problems are expected with consumers, because they can remove the tags with ease. There is no use of the tags for manufacturing control this way, but only in the successive distribution processes.

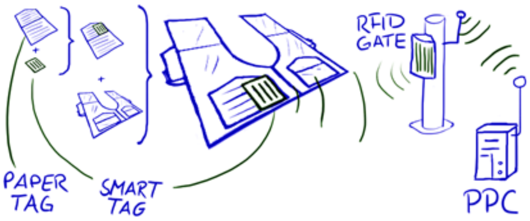

Fig.6 Autonomous PPC – Intelligent Garment.

Fig.7 shows an approach of autonomous control in apparel manufacturing, which takes into account the previous discussion. The fabric is cut and the parts are put into an intelligent trolley. This trolley can be used in a highly flexible way. It is equipped with a smart label that has a display made of digital paper to show its status, as well as product and processing information about the goods inside [25]. The trolley is able to count and check the number of parts inside, e.g. by weighing, light barrier, or pushbutton. The pushbutton is operated by a human worker and can be used to track the amount of parts that are reduced to waste, too. The information held by the intelligent trolley is updated via wireless communication technology. The trolley does not necessarily need separate energy supply, if the tag is powered by a corresponding communication device, like a RFID reader, or a wireless electricity transmission systems (WE) is employed [26].

Each lot of semi-finished parts is now traceable within the manufacturing process. Nevertheless, caution must be taken by workers, when pushbuttons are used to count parts being put in or removed from the trolleys. The trolley's smart label decides which work place should be used next by using a certain decision strategy. Decisions can be made each time the tag is powered, e.g. when it is placed at a wireless energy transmission terminal at the beginning and the end of a working place.

Quality gates are used to check the product and the process quality. One example is verification of the number of garment parts located in a trolley compared to the number noted at the intelligent label. A trolley being emptied at the beginning of a manufacturing line can transfer lot-related information to a trolley receiving the recently processed parts at the end of the line. Another smart label is plugged at the garment in combination with the common garment label at the end of the manufacturing process. The lot related information is transferred from the latest trolley to the garment's label.

The combination of all actions allows tracking, tracing and autonomous control of each lot of semi-finished parts at the manufacturing site. Additionally, the final tag provides the history of each lot's process and enhances each single garment to an autonomous logistic object in the successive supply chain.

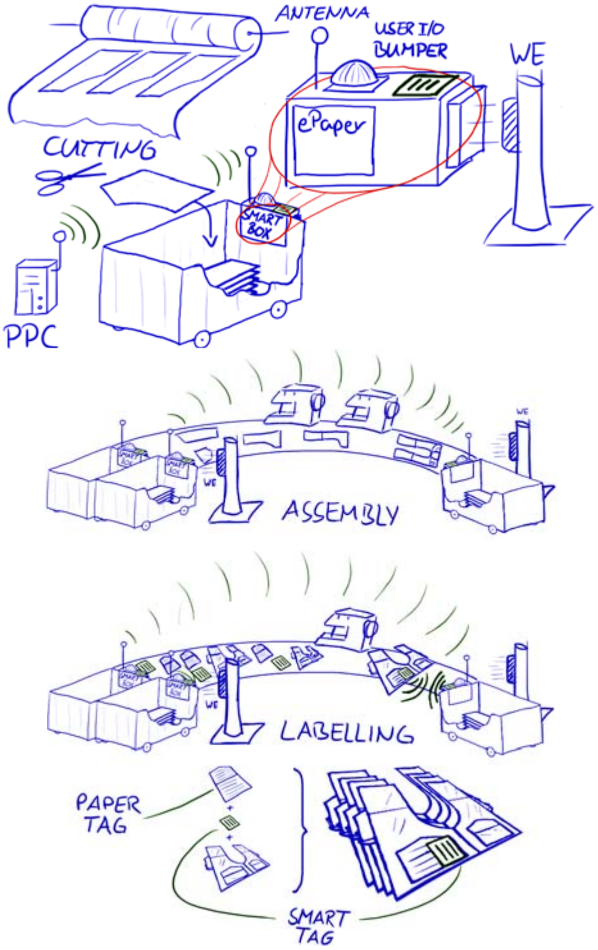

Fig.7 Autonomous PPC – Intelligent Manufacturing Lot and Intelligent Garment.

5 Conclusion and Outlook

Based on a case study, specific problems of the apparel industry have been denoted. The first problem addresses the inflexibility of the manufacturing processes due to static resource allocation and big lot sizes. Miscounting of apparel quantity causes further errors in the following steps in the supply chain. We proposed a hub-architecture that is based on identifiable lots moving autonomously through the manufacturing process. Trolleys and RFID gates provide hub services to the lots.

Further research has to be carried out to analyze the feasibility of the described scenario in detail with simulation studies and in real apparel manufacturing processes. A closer look has to be taken at the required infrastructure and its configuration, as well as at analyzing costs and benefits of the proposed solution.

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