Computers in Industry 82 (2016) 82–94

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

Effects of combining product-centric control and direct digital manufacturing: The case of preparing customized hose assembly kits

Jouni Lyly-Yrjänäinen[a], Jan Holmström[b,*], Mats I. Johansson[c], Petri Suomala[a]

[a] Tampere Univesity of Technology, Tampere, Finland
[b] Aalto University School of Science, Espoo, Finland
[c] Chalmers University of Technology, Ghotenburg, Sweden

ARTICLE INFO

Article history:
Received 27 May 2015
Received in revised form 1 March 2016
Accepted 30 May 2016
Available online xxx

Keywords:
Product centric control
Direct digital manufacturing
Planning simplification
Make-to-order
Kitting
Case study
Design science approach

ABSTRACT

The case study presents the effects of combining product-centric control and direct digital manufacturing (DDM) in the preparation of customized assembly kits. The theoretical contribution of the paper is in describing a combinatorial innovation in operations and production management: how to use product-centric control to make DDM highly efficient when there are many generic and partly generic production resources. Evidence is found of many beneficial outcomes such as waste reduction, simplified planning, and improved customer responsiveness for the case of preparing customized assembly kits for hydraulic hoses.

1. Introduction

Innovative and more efficient ways of working can be found through novel combinations of available solutions [5]. A previous example from the operations and production management literature is Tovinger and Bohn's [56] responsive and efficient solution for the assembly of electronics, combining material tracking and set-up time-reduction techniques in an innovative way. In this paper, we present One-Touch Production, an operational innovation combining direct digital manufacturing (DDM) [20,27] and product-centric control [37] in the production of assembly kits.

Recently, the range of DDM technologies has increased significantly with the advancement of 3D printing [27]. DDM technologies are technologies that include both novel 3D printing and the more conventional digitally controlled machines. The need for tooling up and setting up is reduced by producing parts that are based directly on a digital model [3]. The implication of the development of DDM technologies is that in an increasing number of situations, it is possible to produce parts directly on demand, without tooling up, setting up, and considering the economies of scale.

The use of manufacturing technologies that rely on tools and set-ups are usually designated as mass-production technologies, but more appropriately, they could be considered as indirect manufacturing technologies. In this type of manufacturing, increasing the batch size of component manufacturing reduces the marginal cost. Gutenberg's printing press is the paradigmatic example of this type of indirect manufacturing. A page from a manuscript is typeset and printed, with significant reductions in the cost per page for larger batches. Printing a batch of 100 title pages is significantly cheaper than printing one copy of a 100-page manuscript. Laser printing is the equivalent example of DDM. The manuscript is printed directly without any set-up or tooling up required. The cost per page for printing a manuscript is not affected by the batch size. Printing 100 title pages of a manuscript is just as expensive as printing a complete 100-page manuscript.

Product-centric control is an emerging approach to simplify materials handling and control, customization, and information sharing in the supply chain. It is based on the unique identification of physical objects to which control instructions are then linked [36]. The basic principle is that the product, while it is in the process of being produced and delivered, itself directly requests processing, assembly, and materials handling from the available providers. The requests are dealt with by service providers without any prior planning and scheduling being required [37].

* Corresponding author.
E-mail address: jan.holmstrom@aalto.fi (J. Holmström).

http://dx.doi.org/10.1016/j.compind.2016.05.009

The proposed advantages of product-centric control derive from its responsiveness to real-world circumstances, reducing the need for both inventory buffers and planning and control, while increasing the utilization of service provider assets and labor [52,46]. Some proposed advantages of product-centric control have been demonstrated (e.g. [40] and simulated (e.g. [42], but have not yet been investigated in a real-life case setting.

The case described in this paper involves a component supplier that produces assembly kits of hydraulic hoses for original equipment manufacturers (OEMs). The OEM customers of the case company have mass-customized products. Product modifications also impact hoses, resulting in variations in the contents of the assembly kits and sometimes even the need to make hoses that have never been manufactured previously. In such a context, kitting from inventory is not possible and direct manufacturing of such customized kits is difficult and costly using traditional production control systems. To overcome the problem, the case company combines digitally controlled machines and product-centric control for the DDM of the hoses in the kits. The company's innovative solution results in significantly lower costs and higher quality than its competitors who rely on approaches that are more conventional.

The purpose of the research is the theoretical elaboration of the application of product-centric control and DDM in the preparation of assembly kits. The study takes a practical relevance perspective and is interested in the mechanism through which outcomes are generated in the problem context of the case [17]. The key finding of the study is that product-centric control for DDM is highly efficient because production resources in the case context are generic or partly generic.

2. Theoretical foundations: the problem in context, interventions, and mechanisms for beneficial outcomes

The review of the previous research is structured using design logic [17] to establish the relevant theoretical foundations of the problem in context, the interventions introduced to address the problem, and the analysis of mechanisms for beneficial outcomes. First, research on the problem in context of more customized end products is reviewed, highlighting the increasing need for using material kitting in assembly. Next, the two interventions introduced in the case study—the direct digital manufacturing of kits and product-centric control—are examined. A gap in the current research was found in terms of understanding the benefits and generating mechanisms from the combination of DDM and product-centric control.

2.1. Problem in context: increasing need for material kitting during assembly

In many industries, product variety is large and has increased over recent decades due to more customer-specific products, e.g. in the automotive industry [2]. This drives the increased use of mixed-model assembly lines, allowing a higher product variety and higher degree of customization [10]. Consequently, due to the increase in product variety, there is a need for many different components at the workstations [32]. This, together with the use of continuous supply and large unit packages for components for the final assembly line, leads to a lack of space in line-side component racks.

To resolve the problem of a lack of space with the continuous supply mode, the alternative materials feeding method of kitting has been introduced in many assembly plants. With kitting, the parts for one or several assembly operations are delivered and presented to the assembler in pre-sorted kits with each kit containing parts for one assembly object. The kits can be presented in a stationary position at an assembly station, or travel along the assembly object [11].

A second driver for assembly kitting is the development of lean production methods and techniques. In the design of lean assembly systems, cellular production is used in many situations, requiring a larger diversity of components at each workstation, while at the same time minimizing waste [45] in terms of handling and movement at the workstations. Kitting as a materials feeding process supports the assembler and reduces unnecessary movement [39,58]. Research shows large performance gains at the assembly stations [18] from introducing kitting, while it also enables more compact workstations [8].

A further driving force for introducing kitting relates to quality [11] and learning aspects [30,41], which have been well reported from lean manufacturing operations, and are a reason why kitting has been used in the electronics industry.

Kitting as a phenomenon has gained increasing attention during the last few years due to the need for kitting in increasingly customized and lean assembly processes. However, this research has primarily focused on the applicability of kitting and on comparing kitting to alternative materials supply methods (e.g. [23,14].

2.2. Interventions

Kitting is often associated with an increased amount of materials handling, requiring time consuming and costly materials picking processes [22]. Increased research effort is thus required regarding the efficient preparation of the kits. The problem concerns the efficient organization of kitting preparation so that it effectively supports customized and lean assembly operations. Next, we will examine research on kitting preparation and the product-centric control of manufacturing and logistics.

2.2.1. Kitting preparation: kitting location and component manufacturing

[24] discuss the performance trade-offs for seven kitting performance variables in three different locations within the plant: (1) at the assembly line, (2) in the main storage area of the assembly plant, and (3) in a separate kit preparation area. They identify the benefits and drawbacks for each kitting location. Kitting operational efficiency and flexibility of kitting are affected by the location of the kitting preparation area, but this is very specific to the particular conditions of each case. The anticipated effect of the preparation location on the quality of the kits is that more resources are required for correcting mistakes where incorrect parts have been delivered from a kit preparation area that is distant from the assembly line [7,12,23].

Kitting can also be conducted by a component supplier or third-party logistics service provider. Öjmertz and Johansson [59] examine five cases of kitting and sequencing operations located differently in the supply chain. Their results indicate that there is a large negative impact on potential efficiency in cases where kitting or sequencing is performed in an intermediate facility. Kitting is equally effective when performed by the supplier as it is when carried out in the assembly plant, as long as the transportation costs are not increased due to the lower density of kits compared to single component packages.

With the preparation of kits, the dominant approach is to pick parts from the inventory using picker-to-parts order picking systems [16]. Research focusing in particular on the preparation of kits is scarce. However, there is research studying the design of materials preparation processes for minimizing waiting times [50] and process performance [12]. The storage assignment of components to minimize kitting times has been extensively studied [13]. [15] reviews information support systems that are