Expert Systems with Applications 40 (2013) 83–95

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

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

Mining transportation logs for understanding the after-assembly block manufacturing process in the shipbuilding industry

Seung-kyung Lee [a], Bongseok Kim [a], Minhoe Huh [a], Sungzoon Cho [a,*], Sungkyu Park [b], Daehyung Lee [b]

[a] *Department of Industrial Engineering, Seoul National University, 1 Gwanak ro, Gwanak-gu, 151-744 Seoul, Republic of Korea*
[b] *Production System R&D Group, Daewoo Shipbuilding & Marine Engineering, Republic of Korea*

ARTICLE INFO

Keywords:
Process mining
Workflow mining
Transportation
Manufacturing process
Shipbuilding industry

ABSTRACT

In the after-assembly block manufacturing process in the shipbuilding industry, domain experts or industrial managers have the following questions regarding the first step in terms of reducing the overhead transportation cost due to irregularities not defined in a process design: "What tasks are bottlenecks?" and "How long do the blocks remain waiting in stockyards?" We provide the answers to these two questions. In the process mining framework, we propose a method automatically extracting the most frequent task flows from transport usage histories. Considering characteristics of our application, we use a clustering technique to identify heterogeneous groups of process instances, and then derive a process model independently by group. Process models extracted from real-world transportation logs, are verified by domain experts and labelled based on their interpretations. Consequently, we conceptualize the "standard process" from one global process model. Moreover, local models derived from groups of process instances reflect unknown context regarding characteristics of blocks. Our proposed method can provide conceptualized process models and process (or waiting in stockyards) times as a performance indicator. Providing reasonable answers to their questions, it helps domain experts better understand and manage the actual process. With the extension of the conventional methodology for our application problem, the main contributions of this research are that our proposed approach provides insight into the after-assembly block manufacturing process, and describes the first step for reducing transportation costs.

1. Introduction

Modern shipbuilding is commonly based on the block construction method, which is a way to prefabricate erection blocks independently in shipyards and then aggregate them into the body of a ship at a dock. As shown in Fig. 1, the after-assembly block manufacturing process is the process of transforming assembly blocks into erection blocks through a set of tasks including inspection, pre-outfitting, blasting, pre-painting, and pre-erection (PE). Going through the sequence of tasks that is defined in a process design, a block is transported among workshops for the tasks using transporters or floating cranes.

In the after-assembly block manufacturing process, blocks ideally should be transported from workshops for a preceding task to workshops for a subsequent task only once in order to achieve minimum transportation cost. However, "what is going on" is different from "what should be done", i.e., a process design (van der Aalst et al., 2003; van der Aalst, Weijter, & Maruster, 2004). In real-world situations, blocks are sometimes transported within a workshop unnecessarily many times. Some blocks are transported to stockyards for waiting workshops with heavy workloads to process other blocks. Furthermore, transportation of some blocks may occur within stockyards in order to transport another into workshops for a subsequent task. Thus, the overhead transportation cost due to such irregular block transportation not defined in a process design is not negligible. Since this transportation cost minimization leads to profit maximization in the shipbuilding industry, it has been recognized as a critical issue by domain experts.

The issue, however, has been unsettled because it is difficult to conceptualize the current status of the process that operates over a large shipyard. Regarding this, domain experts have the following questions: *"Which tasks are bottlenecks?"* and *"How long do blocks remain waiting in stockyards?"* That is, in order to reduce the gap between what is going on and what should be done with feedback control, it should be recognized how the after-after-assembly block manufacturing process operates and its performance should be analyzed (Beckett, Wainwright, & Bance, 2000; Negash, 2004). Fortunately, when workers used transporters for block transportation, they manually record information about workshops and times for a block to be loaded and unloaded, and this data has been collected in a database. Hence, in this paper, starting from the fact that such

* Corresponding author.
E-mail addresses: sklee83@snu.ac.kr (S.-k. Lee), kiolol2@gmail.com (B. Kim), dninb.kr@gmail.com (M. Huh), zoon@snu.ac.kr (S. Cho), songquepark@dsme.co.kr (S. Park), dhlee8@dsme.co.kr (D. Lee).

0957-4174/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.eswa.2012.07.033

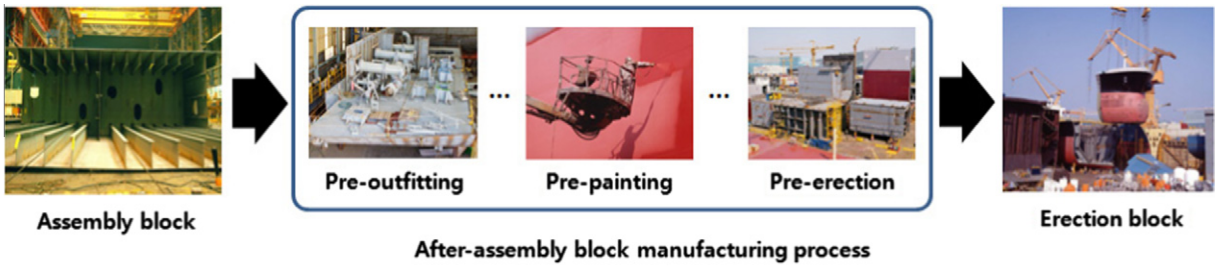

Fig. 1. After-assembly block manufacturing process.

transportation logs are equivalent to event logs with dependency among events, i.e., tasks in the process, we analyzed the transportation log data from the viewpoint of the process mining methodology in order to find answers to the aforementioned questions.

Process mining is general methodology used to extract a process model from event log data, and aims to understand "what is really going on" (Reijers et al., 2007; Tiwari, Turner, & Majeed, 2008; van der Aalst et al., 2003). It is assumed that a time-ordered sequence of event logs (often referred to as "history", "audit trail", "transaction log" (Reijers et al., 2007)) related to a block, each including a task and its performed time, is collected in the form of one case, which is referred to as one process instance based on a process design. In our application, each case is identified by a unique block number, i.e., a block identifier. In other words, each block is processed through a process instance complying to a process design. In this way, we interpret transportation log data as a set of actual task flows for all blocks, i.e., process instances and then derive a process model well-describing process instances from the viewpoint of the process mining methodology (Agrawal, Gunopulos, & Leymann, 1998; Tiwari et al., 2008; van der Aalst et al., 2003). Moreover, a process model represented as a directed graph can be derived using the association rule analysis. The most frequent task flows are consequently "what is going on" in the after-assembly manufacturing process.

And in our application, it is unreasonable to assume that all of the blocks forming one ship are homogeneous and task flows for them comply to a unique process design. This assumption is quite conventional in most research related to the process mining methodology. Accordingly, conventional process mining approaches assume that processing all blocks is based on one process design, and then extract one process model from process instances. However, as pointed out before, it may not always be possible to assume the existence of a single process design (Hwang, Wei, & Yang, 2004; Tiwari et al., 2008). In our application, blocks that cover various parts of a ship are obviously heterogeneous and require different process designs according to the characteristics of the blocks. Related to this point, Greco, Guzzo, Pontieri, and Saccà (2004) used an algorithm for clustering process instances in order to identify different patterns of process instances and then extracted distinctive process models separately from the patterns of process instances. In this way, considering the characteristics of our application, we also use a clustering technique in order to identify groups of process instances so that process instances within one group are more similar to each other than to ones in other groups in terms of the set of performed tasks. We then derive actual process models from the process instances separately by group. It is able to help better understand and manage some heterogeneous patterns of process instances, related with the process monitoring and controlling issue (Bose, 2006; Kang, Kim, & Kang, 2012).

The remainder of this paper is organized as follows. In Section 2, we explain the process mining methodology based on event log data. In Section 3, we propose transportation log-based process mining methods. In Section 4, we provide answers to the questions, applying the proposed method to real-world transportation log data and interpreting the results with domain experts. Finally we conclude the paper in Section 5.

2. Related work: Event-based process mining

An input in the process mining methodology is defined as a set of actual task flows, i.e., process instances complying to a process design, forming a time-ordered sequence of event logs (Schimm, 2004). Moreover, we assume the existence of a process design in Fig. 2 as an example in order to discuss the event-based log data. In this paper, the process is presented as a directed graph, which is the most common form of graph oriented meta-models (Agrawal et al., 1998; Tiwari et al., 2008), although there are more powerful

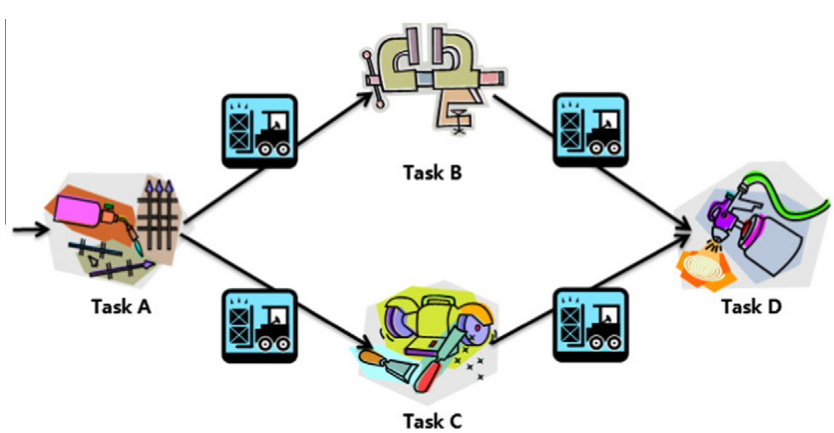

Fig. 2. Process design represented as a directed graph.