Engineering Applications of Artificial Intelligence 30 (2014) 49–62

Contents lists available at ScienceDirect

Engineering Applications of Artificial Intelligence

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

Automated guided vehicles fleet match-up scheduling with production flow constraints

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ARTICLE INFO

Article history:
Received 11 May 2013
Received in revised form
27 December 2013
Accepted 4 February 2014
Available online 1 March 2014

Keywords:
Material handling
AGVs fleet assignment
Sizing and scheduling
Cyclic schedule
Declarative modeling

ABSTRACT

The paper describes a Multimodal Transportation Network (MTN) in which several unimodal networks (Automated Guided Vehicles (AGVs), hoists, lifts, etc.) interact with each other via common shared workstations as to provide a variety of demand-responsive material handling operations. The material handling transport modes provide movement of work pieces between workstations along their manufacturing routes in the MTN. The main contribution of this work is the solution to a constraint satisfaction problem aimed at AGVs fleet match-up scheduling while taking into consideration assumed itineraries of concurrently manufactured product types. In other words, assuming a given topology of the MTN and schedules of operation sequences modeling concurrently manufactured product types, the main objective is to provide a declarative framework aimed at determining conditions allowing one to adjust the AGVs fleet schedule due to the timetable of operations executed in an assumed multi-product manufacturing environment.

1. Introduction

The productivity of an AGV-served flow shop repetitively producing a set of different products, depends on both the job flow sequencing (maximizing throughput or minimizing cycle time), and the material handling system required to achieve a pre-specified throughput, i.e. AGVs fleet sizing, assignment and scheduling (Abara, 1989; Clarke et al., 1996; Hall et al., 2001). So, assuming a deterministic system where demand is known in advance and the processing times of each job on each machine is a known constant, in order to improve its productivity, the AGVs fleet size and the scheduling/dispatching influence on the system throughput are usually examined (Abara, 1989; Chelbi and Alt-Kadi, 2004; Deris et al., 1999; Hane et al., 1995; Fazlollahtabar and Saidi-Mehrabad, 2013; Qiu et al., 2002).

A number of papers are concerned with the fleet assignment problem (Abara, 1989; Clarke et al., 1996; Hane et al., 1995), and maintenance planning (Chelbi and Alt-Kadi 2004; Deris et al., 1999; Papakostas et al., 2010). However, few papers have considered the combination of fleet assignment and maintenance planning (Clarke et al., 1996; Moudani and Mora-Camino, 2000). Most publications on fleet assignment are focused on the fleet operation cost minimization (Abara, 1989; Hane et al., 1995). Some papers on maintenance planning have focused on planning maintenance tasks to minimize the maintenance cost (Chelbi and Alt-Kadi, 2004; Deris et al., 1999; Papakostas et al., 2010). Few papers have considered the integration of fleet assignment and maintenance planning (Clarke et al., 1996; Moudani and Mora-Camino, 2000). The inventory policy with preventive maintenance consideration is mostly studied for production systems (Chelbi and Alt-Kadi, 2004; Rezg et al., 2008; Vaughan, 2005). Because of unpredicted situations, rescheduling is required to deal within an online mode to support decision making. Therefore, scheduling and rescheduling fleet assignment and maintenance planning and inventory policy are implemented in task dedicated decision support systems (Moudani and Mora-Camino, 2000).

As most real-life available manufacturing processes manifest a cyclic steady state, an alternative approach to AGVs fleet dispatching and scheduling, e.g. following from the Systems of Concurrently flowing Cyclic Processes (SCCP) concept (Abara, 1989; Sharma, 2012; Von Kampmeyer, 2006) can be considered as well. The problems arising concern material transportation routing and scheduling are NP-hard in nature (Clarke et al., 1996). Since the steady state of production flows has a cyclic character, hence servicing them AGV-served transportation processes (usually executed along loop-like routes) also encompasses cyclic behavior. That means, the periodicity of a Flexible Manufacturing System (FMS) (Trouillet et al., 2007) depends on both the periodicity of the

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http://dx.doi.org/10.1016/j.engappai.2014.02.003
0952-1976

production flow cyclic schedule and, following this schedule, the AGVs periodicity. Of course, the Multimodal Transportation Network (MTP) (Bielli et al., 2006) throughput is maximized by the minimization of its cycle time.

Many models and methods have been considered to date (Levner et al., 2010; Fazlollahtabar and Saidi-Mehrabad, 2013). Among these, the mathematical programming approach (Abara, 1989; Vaughan, 2005), max-plus algebra (Polak et al., 2004), constraint logic programming (Bocewicz and Banaszak, 2013a, 2013b; Bocewicz et al., 2012) evolutionary algorithms (Słowik, 2011), Petri nets (Song and Lee, 1998) and multi-agent systems (Bernaer, 2006) frameworks are the more frequently used. Most of these methods are oriented at finding a minimal cycle or maximal throughput while assuming deadlock-free processes flow.

In that context our main contribution is to propose a declarative framework aimed at refinement and prototyping of the cyclic steady states for concurrently executed cyclic processes modeling material handling systems. These systems are of the type such as AGVs fleets in the FMSs and are frequently encountered in industry. The following questions are the main focus of the research: Can the assumed material handling system (e.g. AGVs) characteristics meet the load/unload deadlines imposed by the scheduled flow of work pieces? Does a given Automated Guided Vehicle System (AGVS) enable to schedule the AGVs fleet so as to ensure lag-free service of scheduled work pieces processing? So, the main question is: Can the assumed AGVs fleet assignment reach its goal subject to constraints assumed on concurrent multi-product manufacturing on hand? In other words, this paper's objective concerns the MTN infrastructure assessment from the perspective of possible FMS oriented requirements imposed by AGVs' fleet assignment, sizing, and scheduling. Due to the complexity implied in answering the above questions, the combined problem remains unsolved for all practical purposes. This is especially problematic as many manufacturing companies would stand to reap considerable rewards through better fleet assignment and scheduling. The presented approach addresses this through solving the combined rather than the separate problems individually.

In that context, the problem considered in this paper can be seen as an extension of the problems formulated in Bocewicz and Banaszak (2013a, 2013b). Specifically, the problem stated in Bocewicz and Banaszak (2013a) assumes a given SCCP network composed of a set of interacting cyclic processes and considers the set of local cyclic processes occurring in the SCCP. The question sought concerns of selection of priority dispatching rules assigned in the course of the step-by-step SCCP network reconstruction, guaranteeing cyclic behavior of each consecutive subsystem. The considered problem belongs to the class of “reverse” ones.

In turn, the problem considered in Bocewicz and Banaszak (2013b) boils down to examining whether sufficient conditions guaranteeing that a given SCCP (supporting the execution of multimodal processes) behaves cyclically exist. A SCCP network composed of a set of interacting cyclic processes and a set of multimodal processes as well as operation times and synchronization protocols are decision variables occurring in those conditions. The considered problem belongs to a class of “straight” ones.

Assuming a given SCCP network, i.e. the set of resources, the set of local cyclic routes, the set of multimodal processes, the set of dispatching rules including ones linking local processes and multimodal ones as well as assuming cyclic behavior of the whole system, the problem boils down to answering the question: What are the local processes operation times guaranteeing their match-up with the multimodal processes schedule. Since the operation times are sought in the course of the step-by-step reconstruction of both the SCCP networks and supporting parts of the multimodal processes (see Bocewicz and Banaszak, 2013b) this is a reverse problem.

The remainder of the paper is organized as follows: Section 2 introduces the AGVs modeled in terms of SCCP. Section 3 provides a problem statement concerning AGVs fleet match-up scheduling with a multi-product manufacturing flow schedule. Then the already stated problem formulated in a declarative modeling framework aimed at AGVs fleet scheduling is considered in Section 4. An illustrative example of the proposed approach is discussed in Section 5 and the concluding remarks are presented in Section 6.

2. Model of AGVS

Automated Guided Vehicle Systems (AGVS) are used for material handling within a FMS, and provide asynchronous movement pallets of products through a network of guide paths between the workstations by the AGVs. Each workstation is connected to the guide path network by a pick-up/delivery station where pallets are transferred to/from the AGVs.

In AGVS literature, most research is related to AGVS design issues, which include determining the number of required vehicles, flow path design and route planning as well as vehicle dispatching and traffic management. Recently, the integrated problem of dispatching and conflict free routing of AGVs, i.e. integrating the simultaneous assignment, scheduling and conflict free routing of the vehicles, is receiving increasing attention. Since, most processes observed in steady state manufacturing are periodic, and therefore follow cyclic schedules cyclic scheduling methods can be considered. Therefore, the proposed cyclic processes modeling approach provides a quite reasonable perspective for cyclic scheduling encompassing the repetitive character of manufacturing processes (Bernaer, 2006; Bocewicz and Banaszak, 2013a, 2013b; Polak et al., 2004).

In order to illustrate the idea standing behind our approach, a case example of a simple FMS is shown in Fig. 1 including some of the design and operational issues that arise in repetitive manufacturing systems served by AGVs moving within loop-like network environment while supporting unidirectional material flows. The concurrent multi-product flows are depicted by bold green, blue, and orange color lines, while the transportation loop-like network are distinguished by double solid line. Both kinds of material (jobs) and transportation (AGVs) flows shown in Fig. 1 can be modeled in terms of SCCPs (Bocewicz and Banaszak, 2013a, 2013b) as shown in Fig. 2. In turn, the SCCP framework provides a formal model enabling to state and resolve problems of AGV fleet size minimization as well as steady state cycle time minimization. The cycle time minimization is required to obtain maximum throughput rate.

Eight *local cyclic processes* are considered, viz. $P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8$. The processes follow the *routes* composed of transportation sectors and machines (distinguished in Fig. 2 by the *set of resources*, $R=\{R_1,\ldots,R_c,\ldots,R_{33}\}$, R_c is the cth resource). Some of the local cyclic processes are pipeline flow processes, i.e. they contain *streams* (representing vehicles from Fig. 1) of the processes following the same route while occupying different resources (sectors). For instance, processes P_4, P_5, P_6 contain two streams: $P_4=\{P_4^1, P_4^2\}$, $P_5=\{P_5^1, P_5^2\}$, $P_6=\{P_6^1, P_6^2\}$, respectively and P_2 contains three streams: $P_2=\{P_2^1, P_2^2, P_2^3\}$, i.e., the processes (vehicles) moving along the same route. The remaining local processes contain unique streams: $P_1=\{P_1^1\}$, $P_3=\{P_3^1\}$, $P_7=\{P_7^1\}$, $P_8=\{P_8^1\}$. In other words, the streams: $P_1^1, P_2^1, P_2^2, P_2^3, P_3^1, P_4^1, P_4^2, P_5^1, P_5^2, P_6^1, P_6^2, P_7^1, P_8^1$ represent the 13 vehicles from Fig. 1. The kth stream of the ith local process P_i is denoted as P_i^k.

Apart from local processes, we consider three *multimodal processes* (i.e. processes executed along the routes consisting of parts of the routes of local processes): mP_1, mP_2, mP_3.