ELSEVIER

Int. J. Production Economics 64 (2000) 49–58

international journal of production economics

www.elsevier.com/locate/dsw

An LP-based approach for loading and routing in a flexible assembly line

Tadeusz Sawik*

Department of Computer Integrated Manufacturing, Faculty of Management, University of Mining and Metallurgy, Al. Mickiewicza 30, 30-059 Krakow, Poland

Abstract

The paper presents integer programming formulations and a heuristic solution procedure for a bicriterion loading and assembly plan selection problem in a flexible assembly line. The problem objective is to simultaneously determine an allocation of assembly tasks among the stations and select assembly sequences and assembly routes for a mix of products so as to balance station workloads and to minimize total transportation time in a unidirectional flow system. In the approach proposed, first the station workloads are balanced using a linear relaxation-based heuristic and then assembly sequences and assembly routes are selected for all products, based on a network flow model. An illustrative example is provided and some computational results are reported. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Flexible manufacturing systems; Loading; Routing; Bi-objective integer programming; LP-based heuristic

1. Introduction

A flexible assembly line (FAL) is a unidirectional flow system made up of a set of assembly stations in series and a loading/unloading (L/U) station, linked with an automated material handling system. The flexible assembly stations (e.g., assembly robots or automatic insertion machines) have a finite work space due to their physical configuration. The component feeding mechanism associated with each assembly task uses some of the finite work space. Therefore only a limited number of tasks can be assigned to a station. When components are all of relatively similar sizes one may assume that each task uses the same amount of the station work space, Under this assumption the finite work space of a station can be refined as its flexibility capacity which specifies the maximum number of tasks that can be assigned to the station. There are negligible setup times between task changes among the tasks assigned to a station, e.g., [1,2].

In a FAL different product types are assembled simultaneously. A typical assembly process proceeds as follows. A base part of a product is loaded on a pallet and enters the line at the L/U station. As the pallet is carried by a conveyor or an automated guided vehicle through a series of assembly stations, components are assembled with the base part. A product may bypass some stations but does not revisit any station. When all the required

* Tel.: + 48.12.644 52 96; fax: + 48.12.617 39 84.
E-mail address: tsawik@wzn4.zarz.agh.edu.pl (T. Sawik)

PII: S0925-5273(99)00043-2

components are assembled with the base part, it is carried back to the L/U station and the complete product leaves the system.

The two main FAL short-term planning issues are loading and routing. Loading determines an assignment of assembly tasks (component feeders and appropriate assembly tools) to stations, whereas routing fixes assembly routes for a set of products to be simultaneously assembled. An assembly route is defined to be a sequence of stations that a product must successively visit to have all its components assembled with the base part.

The loading and routing decisions immediately precede detailed scheduling of an assembly process. Once the loading and routing problem has been solved, an assembly schedule will be obtained by solving the corresponding machine and vehicle scheduling problem in a convenient way, e.g., [3–5]. Given the assembly routes for a mix of products, for each task of each single product and the selected machine, its start, completion and release times are determined along with the corresponding times of any required movements between the stations. The scheduling issues, however are not considered in this paper.

The objective of the FAL loading and routing is to assign tasks and products to stations with limited capabilities in order to equalize station workloads and to minimize interstation product movements, subject to precedence relations among the tasks for selected assembly plans and a mix of product types.

Similar loading and routing problems are considered, for example in [3,6]. In [3] workload balancing and part transfer minimization is formulated in terms of particular capacity assignment problem with continuous variables and with no limitations on station work space available. In [6] an FMS loading problem is considered as a single objective part movement minimization subject to additional constraints on maximum workload of each machine, assuming that some upper bounds on the workloads are given. The problem was formulated as a quadratic programming problem. The quadratic terms were linearized using two different approaches and the resulting 0–1 linear program was solved using Hyper LINDO optimization package.

Productivity of a flexible assembly system can be enhanced by allowing greater flexibility at the short-term planning. There are two sources that may increase the flexibility of the loading decision making: flexibility in the product assembly plans and duplicate assembly task assignments. In this paper both options are considered simultaneously. One can argue that fixing the sequence of assembly tasks for each product before the loading stage, without the knowledge of the task assignments and the product mix to be simultaneously assembled in a flexible flow line, decreases the chances of getting optimal or good workload balance. Avoiding premature selection of product assembly sequences leads to a better balancing methodology. When balancing an FAL all duplicate task assignments and product assembly routes that simultaneously satisfy the assembly precedence relations for all products in a unidirectional flow line should be considered.

In the balancing problem studied in this paper alternative assembly sequences (i.e., alternative chain-type precedence relations among the assembly tasks) for each product are assumed to be available (e.g., [7]) as well as duplicate assignments of assembly tasks to different stations are allowed, which leads to an enhanced routing flexibility (cf. [8]). The problem considered is actually a combination of simultaneous machine loading, product routing and assembly sequence selection. The problem is an extension of the loading problem with prefixed single assembly sequence for each product, presented in [9,10] for a general flexible assembly system, where multidirectional product flows and revisiting of stations are allowed.

The modelling and solution approach proposed in this paper is similar to that given in [10] for a general flexible assembly system. The FAL loading, assembly routing and assembly sequence selection problem is formulated as a bicriterion integer program with the objectives of balancing station workloads and minimizing total transportation time. A two-level solution procedure is proposed. First, the station workloads are balanced using a linear relaxation-based heuristic and then the best assembly sequences and assembly routes are selected based on a network flow model to minimize total transportation time.