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Int. J. Production Economics 101 (2006) 312–328

international journal of production economics
www.elsevier.com/locate/ijpe

Meta-heuristics from nature for the loop layout design problem

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Received 9 February 2004; accepted 25 January 2005
Available online 18 March 2005

Abstract

The loop-layout design problem (LLDP) arises when the machines in a flexible manufacturing system (FMS) are arranged in a closed ring-like network and the materials are transported around this network in only one direction. Evaluation of this layout is usually performed by estimating the traffic congestion, i.e., the number of cycles spent by each part in the network until its processing through the required machines is completed. The problem is known to be NP-hard and thus the right way to proceed is through the use of heuristics techniques. This paper addresses the unidirectional LLDP using a differential evolution algorithm (DEA); a modern meta-heuristic from the field of evolutionary computation. The performance of the DEA is measured through multiple characteristic experiments and compared to that of other known meta-heuristics such as genetic algorithms and simulated annealing.

Keywords: Loop-layout problem; Differential evolution; Meta-heuristics; Combinatorial optimization; Manufacturing optimization

1. Introduction

Flexible manufacturing systems (FMS) play a crucial role in modern complex production lines. Such systems generally consist of a group of machines capable of performing a number of different operations, interconnected through an automated parts-transportation and handling mechanism all operating under the hierarchical control of a common computer system. An important factor in designing a FMS is the determination of an effective layout of the machines, i.e., an optimum arrangement of the machines in the shop floor so that to provide efficient operation (Kusiak and Heragu, 1987). The layout of the machines has a significant impact to the material-handling cost, the time of processing, the throughput of the production system, and therefore affects the overall productivity of the FMS. Good surveys on the general layout design problem for FMS can be found in Kusiak and Heragu (1987), Kusiak (1990), Hassan (1994, 1995), Meller and Gau (1996), Ioannou and Minis (1998).

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0925-5273/$ - see front matter
doi:10.1016/j.ijpe.2005.02.001

The layout of machines in a FMS is typically determined by the type of material-handling device used such as material-handling robots, automated guided vehicles (AGVs), gantry robots, etc. In practice, the most commonly used types of machine layouts are the following (see Fig. 1): the linear single-row layout (Fig. 1(a)), the linear double-row (Fig. 1(b)), the cluster layout based on gantry robot (Fig. 1(c)), the semi-circular layout with a single robot, (Fig. 1(d)), and the closed-loop layout (Fig. 1(e)). In the first two layouts (Figs. 1(a)–(b)) an AGV transports parts between the machines moving in both directions in a straight line. The third machines layout (Fig. 1(c)) based on a gantry robot is used when the space in the shop floor is limited. In the fourth layout (Fig. 1(d)) a material-handling industrial robot carries parts between the machines traversing with its end-effector a semi-circular (pre-specified) trajectory. While, in the closed-loop layout, a conveyor moves in a closed-loop rail in only one direction transporting parts among the machines.

This work addresses the unidirectional loop-layout design problem (LLDP), i.e., the problem of designing loop-layout-manufacturing systems of the form shown in Fig. 1(e). The problem has been proven to be NP-hard (Leung, 1992), meaning that there is no algorithm that can solve it in polynomial time, unless it is proved that $P = \mathrm{NP}$ (Garey and Johnson, 1979). In contrary to other layout configurations, there are at least two main factors that make loop layouts attractive for use (Afentakis, 1989): firstly, due to their relatively low

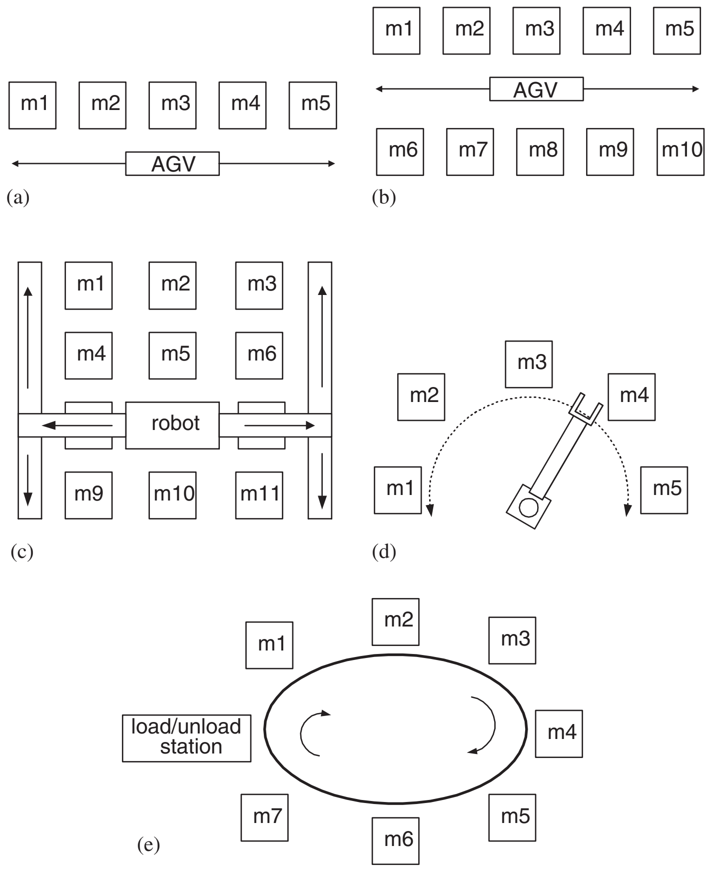

Fig. 1. Forms of machines layouts in a FMS with respect to the various types of the material-handling devices: (a) single-row layout, (b) double-row layout, (c) cluster layout, (d) semi-circular layout, and (e) closed unidirectional loop layout.