Computers & Industrial Engineering 63 (2012) 98–108

Contents lists available at SciVerse ScienceDirect

Computers & Industrial Engineering

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

A revised electromagnetism-like mechanism for layout design of reconfigurable manufacturing system

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ARTICLE INFO

Article history:
Received 8 December 2010
Received in revised form 15 January 2012
Accepted 17 January 2012
Available online 1 February 2012

Keywords:
Electromagnetism-like mechanism
Layout design
Automated guided vehicle
Variable neighbourhood search

ABSTRACT

The layout design problem is one of the most important issues for manufacturing system design and control. A revised electromagnetism-like mechanism (REM) is proposed in this paper for the layout design of reconfigurable manufacturing systems utilizing automated guided vehicle. First, the formal model considering both loaded and empty flows is given. Then the REM is developed to solve the proposed model. In the REM, particles are encoded discretely. The charge of a particle is calculated according the total material handling cost of the particle. In the local search procedure, variable neighbourhood search strategy based on Hamming distance is adopted. In the moving procedure, the particles are moved according to the ordering of each element. To verify the effect of the proposed method, several computation cases are carried out. The computation results show that the proposed method is able to get optimal solutions for small scale problems and near optimal solutions within limited computation time for large scale problems. This indicates that the proposed method is effective and efficient.

1. Introduction

Layout design is one of the most important issues for manufacturing system design and control. In traditional manufacturing system, the layout is rarely changed after the initial system design. As the market demands are changing rapidly nowadays, manufacturers are required to provide various products within limited time in a cost-effective manner. So a new manufacturing paradigm, named as reconfigurable manufacturing system (RMS), is developed to response to such requirements (Bi, Lang, Shen, & Wang, 2008; Mehrabi, Ulsoy, & Koren, 2000). RMS undergoes frequent configuration changes to adapt to different production requirements. To raise efficiency and to reduce manufacturing cost, the layout of RMS should be redesigned and reconfigured frequently as well. The material handing cost is a major part of the total cost in the manufacturing system. It is shown that 20–50% cost is material handling cost, and proper layout of machines may reduce 10–30% material handling cost (Tompkins & White, 1996). Layout design affects the total material handling cost greatly. The layout design problem has been discussed early (Koopmans & Beckmann, 1957) and a lot of works have been carried out (Drira, Pierreval, & Hajri-Gabouj, 2007). The layout design problem was often modelled as Quadratic Assignment Problem (QAP) (Drira et al., 2007). It is an NP-complete problem, which is very difficult to solve. The optimal methods can only solve small size problems (Burkard et al.,1991; Loiola, Abreu, Boaventura-Netto, Hahn, & Querido, 2007). Most previous works concentrate on the static or dynamic layout design problems and only a few concerns on reconfigurable layout design problem. Meng, Heragu, and Zijm (2004) discussed the reconfigurable layout design problem and they gave out the characteristics of reconfigurable layout design problem. The production information of RMS is usually limited and uncertain and it is often the case that we just know the production requirements for the current and upcoming production period. Thus we have to design the system layout with limited information so as to minimize the total cost including the material handling cost, work in process cost, delay cost, device reconfiguration cost an so on. For this purpose, Meng et al. (2004) proposed a process to estimate the stochastic performance measures as well as determined ones of a layout. With the advancement of manufacturing technology, such as the Reconfigurable Machining Tools (RMTs) and modularization of manufacturing hardware and software, it is possible to redesign and reconfigure the layout of RMS within limited time and moderate cost. As the automated guided vehicle (AGV) is flexible to change its route, it is fit for RMS material handling requirements. We deal with the layout design of reconfigurable manufacturing system utilizing AGV as the material handling method. The material handling pattern of AGV is different to that of fix material handling one such as transfer belt. The empty travel of AGVs should be taken into account. So in our model, the empty

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doi:10.1016/j.cie.2012.01.016

travel distance is considered in the objective function. As RMS requires frequent configuration change, the computation time for layout design is limited. The optimal methods do not fit for large scale problems, so heuristic methods are more appropriate. Many heuristic methods have been proposed to solve layout problems (Aiello, Enea, & Galante, 2006; Dunker, Radons, & Westkamper, 2005; Rajasekharan et al., 1998). But the solution quality is not satisfactory yet. In most works on QAP, the distance between the central positions of the workstations is taken as the distance between workstations. And few works consider the empty travel distance of AGV. In this paper, we take the total segment length travelled by AGV as the distance between workstations. And we consider the empty travel of AGV. Thus the computation of the proposed model is much more complex than those of previous models. So method with quick search speed and high solution quality is desirable. Electromagnetism-like mechanism is a new heuristic method for global optimization (Birbil & Fang, 2003; Birbil, Fang, & Sheu, 2004; Guan, Dai, & Li, 2011). It is expected to be efficient and effective. As the cost is major concern of manufacturers, the solution quality of layout design is critical. To raise solution quality, so as to reduce manufacturing cost, we try to solve the layout design problem from two aspects. First we construct a model which is more practical to the real system. Then we proposed an efficient heuristic method to solve the proposed model.

2. Problem statement

2.1. Production scenario

We deal with the production pattern of RMS with changing production requirements during the long period, but the production is relative stable within a certain production period, for example one or several months. And we suppose that it is relatively easy to change the layout of workstations with limited cost and time. The target RMS production scenario is given as follows. At the initial period, the layout is not given yet. We have to design the layout with current production requirement. The production requirement can be denoted by the from-to table of loaded flows between workstations. Layout design procedure gives the best layout for current production situation. Then the workstations are located according to the layout design result and the system begins to produce current products. After a certain production period, new production requirements arrive. Then the layout may be redesigned and reconfigured with new loaded flows and previous layout, so as to reduce total material handling cost. The reconfiguration of workstation in the system may concern some reallocation and reset cost, which is called reconfiguration cost in this paper. At this time, the reconfiguration cost of workstations should be taken into account. After the layout is redesigned and relocated, the system begins to produce new products. The system operates as above circle to deal with changing production requirements. The production scenario is shown in Fig. 1.

Based on above production scenario, we propose a framework to handle it, which is shown in Fig. 2.

2.2. Layout design model

The layout design problem is often modelled as Quadratic Assignment Problem (QAP). We deal with the layout design problem of RMS using AGV. It is different to that utilizing fixed material transfer pattern such as transfer belt. AGV is more flexible and it can be used in different layout and change its transfer path easily. But AGV may take some empty travels, which should be taken into account. So the layout design model of RMS with AGV is much more complex.

For our layout design problem, we make following assumptions:

(1) The number of workstations is the same as that of allocable sites.
(2) A site can be allocated one and only one workstation and one workstation can be allocated to any one site.
(3) There is one pickup location and one delivery location for each site.
(4) The path segments are bidirectional and the AGVs travel along the shortest path.
(5) Only the workstation changing its location takes reconfiguration cost and the reconfiguration cost is the same for all workstations.
(6) The AGVs can carry one workpiece at a time.
(7) The buffer is assumed enough to accommodate workpieces and the size of the buffer is not taken into account.
(8) The operation matters such as conflict or collision of AGVs are not considered.

An example system site layout is shown in Fig. 3. There are four sites S1–S4 assignable. We assumed that a workstation can be allocationed to any site. This maybe not the case in realistic problems, but it is easy to add some constraints for some workstations not allocable to some sites. There is one pickup location (output point, as shown in white circle in Fig. 3) and one delivery location (input point, as shown in shadowed circle in Fig. 3) for each site. Generally, the pickup location and the delivery location of a site are at different positions. And there are connection nodes (shown as squares in Fig. 3). There are segments connecting nodes and P/D locations. The AGVs go to the pickup location of the source workstation and travel to the delivery location of the destination workstation along the path segments to transport workpieces between workstations. As the pickup and delivery locations are different, we have to consider the empty travels of AGVs. We mainly consider the material handling cost in our problem, and the AGVs' travels are close to the realistic conditions. Suppose at one production period, the loaded flows are given in Table 1. And the current layout is determined by the variables H^0_{ws}. If workstation w is allocated to site s, $H^0_{ws}=1$, otherwise $H^0_{ws}=0$. If W1 is located at site S1, W4 at S2, W2 at S3, and W3 at S4, then the layout can be denoted as [1 4 2 3]. The problem is to allocate workstations W1–W4 to sites S1–S4 so as to minimize the total material handling cost.

After the workstations are allocated, the AGVs travel along the shortest paths to transport workpieces from pickup locations of the source workstations to delivery locations of the destination workstations. If the workstations are allocated as W1–S1, W2–S2, W3–S3 and W4–S4. If a AGV transprots one workpiece from W1 to W4 and then transport another one from W3 to W2, then its travel may as follows (denoted by node numbers): 6–7–8–9–12 (Path1, from P1 to D4); 12–16–15 (Path2, goto P3); 15–16–9–10 (Path3, goto D2). Obviously, the AGV takes an empty travel: Path2. Our objective is to design the layout so as to minimize the total material handling cost, which incudes the cost caused by the

Table 1
An example of loaded flows.

From	To			
	1	2	3	4
1	0	0	777	0
2	835	0	0	545
3	0	780	0	558
4	389	0	0	0