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Multi-objective fuzzy disassembly line balancing using a hybrid discrete artificial bee colony algorithm

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ABSTRACT

This paper presents a fuzzy extension of the disassembly line balancing problem (DLBP) with fuzzy task processing times since uncertainty is the main character of real-world disassembly systems. The processing times of tasks are formulated by triangular fuzzy membership functions. The balance measure function is modified according to fuzzy characteristics of the disassembly line. A hybrid discrete artificial bee colony algorithm is proposed to solve the problem whose performance is studied over a well-known test problem taken from open literature and over a new data set introduced in this study. Furthermore, the influence of the fuzziness on the computational complexity of HDABC is evaluated and the solution quality of the proposed algorithm is compared against discrete and traditional versions of the artificial bee colony algorithm. Computational comparisons demonstrate the superiority of the proposed algorithm.
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1. Introduction

At a time when economic and ecological resources are rapidly depleted, product recovery that aims to minimize the amount of waste sent to landfills is gaining a lot of importance. Comprehensive reviews of environmentally conscious manufacturing and product recovery can be found in [1,2]. Product recovery consists of several steps in which the first crucial step is disassembly [3]. Disassembly is a methodical extraction of valuable parts [4] from discarded products through a series of operations. Some of the objectives of disassembly are given as follows [5]: recovery of valuable parts and subassemblies, removal of hazardous parts, extraction of parts from the remainder of the product which can be sent to inventory for future use, achieving environmentally friendly manufacturing standards, retrieval of parts or subassemblies of discontinued products to satisfy a sudden demand for these parts, decreasing the amount of residue to be sent to landfills. Thus the design of an efficient disassembly line has a considerable industrial and environmental importance.

Disassembly Line Balancing Problem (DLBP) is a multi-objective problem as described in [6] and has been mathematically proven to be NP-complete in [7] making the goal to achieve the optimal balance computationally expensive. NP-complete or NP-hard terms are the ways of showing that certain classes of problems are not solvable in realistic time [8]. Exponential time complexity of exhaustive search limits its application to large sized instances although it works well in obtaining optimal solutions for small sized instances. An efficient search method, therefore, needs to be employed to attain an (near) optimal solution. The ways of approaching to this combinatorial optimization problem in the literature can be divided into two categories; mathematical programming techniques [9–12] and metaheuristics [7,13–24]. Metaheuristics are more popular since the problem quickly becomes unsolvable with mathematical programming techniques for a practical sized problem. See [25] for more information on DLBP.

Disassembly operations have unique characteristics and cannot be considered as the reverse of assembly operations. Please see [17] for details. Although there are significant differences between assembly line balancing and disassembly line balancing problems, disassembly line balancing literature has been building up on top of the assembly line balancing literature since there are also some similarities between them. The literature of fuzziness in assembly line balancing is of primary interest of this study. The fuzziness in the literature of assembly line balancing was first mentioned in [26,27] by solving a simple fuzzy assembly line balancing

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problem applied to a single product example. A fuzzy mixed model line balancing problem with a fuzzy binary linear programming model was considered in [28] using a heuristic solution approach that deals with fuzzy processing times. Fuzzy multi objective two-sided assembly line balancing problem was solved using a bees algorithm in [29] with three fuzzy goals: maximize the work slackness index, minimize the total balance delay and maximize the line efficiency. Genetic algorithms were used to solve multi objective fuzzy assembly line balancing problem type 2 [30] and fuzzy assembly line balancing problem type E [31].

In disassembly, there is a high degree of uncertainty in the structure and the quality of the returned products. The structural unknowns of end-of-life (EOL) products may create other uncertainties, such as estimation of disassembly task time of each part due to both machine and human factors. To the best of our knowledge, there is only one previously published work [32] that deals with fuzziness in mixed model disassembly line balancing problem using binary fuzzy goal programming. Yet, in this study, in order to deal with imprecise data, fuzzy numbers are introduced to represent the processing time of each job. Thus, a fuzzy disassembly line balancing model is obtained. The consideration of fuzziness for the solution of disassembly line balancing problem is of immense interest since the data obtained from more realistic situations are imprecise and uncertain. Aiming to fill this gap, this paper introduces a new hybrid discrete artificial bee colony algorithm (HDABC) for solving the multi objective fuzzy disassembly line balancing problem (FDLBP). The fuzzy processing times of disassembly tasks are represented by triangular fuzzy membership functions. Two different evaluation mechanisms are used in the proposed algorithm: lexicographic method that focuses on each objective according to predefined priorities and fixed weighted method that tries to optimize each conflicting objective concurrently with the hope of constructing an efficient Pareto frontier. The performance of HDABC is compared against discrete and traditional versions of the artificial bee colony algorithm on two different cases. Moreover, the influence of the fuzziness on the computational complexity of HDABC is evaluated.

2. Fuzzy disassembly line balancing model

2.1. Notation

π	a solution in VNS
$\widetilde{BD}$	fuzzy balance delay time
$\widetilde{BE}$	fuzzy balance efficiency
$c_{\max}$	maximum cycle time
$\tilde{c}$	fuzzy cycle time
d_i	demand quantity of part i requested
f_s	the nectar amount (i.e., the fitness value) of a food source (s) in the ABC algorithm
g	current iteration (generation) number of the algorithm
h_i	binary value; 1 if part i is hazardous, else 0.
i	part identification, task count (1, . . ., n)
imp	non-improved iteration count
IP	set (i, j) of parts such that task i must precede task j
j	part identification, task count (1, . . ., n)
k	workstation count (1,. . .,m)
LB_j	lower bound for dimension j
m	number of workstations required for a given solution sequence
n	number of parts for removal (dimension of the problem)
P_s	the selection probability of a food source (s)
ps	population size of the ABC algorithm
PS_i	ith part in a solution sequence
$r_{0,1}$	a uniformly distributed real number in [0,1]
$r_{-1,1}$	a uniformly distributed real number in [−1, 1]
s	a solution (bee) count (1, . . ., ps)
$\widetilde{SI}$	smoothness index
$\widetilde{ST_j}$	total fuzzy station time; the sum of processing time at workstation j
t_i	part removal time of part i
UB_j	upper bound for dimension j
x_{jk}	binary value; 1 if part j is assigned to station k, 0 otherwise.
y_{ij}	binary value; 1 if task i is executed after task j, 0 otherwise.

2.2. Problem formulation

Assumptions of multi objective fuzzy disassembly line balancing problem are given as follows: there is only one type of product in the disassembly line; complete disassembly is performed; part removal times are known and assumed to be fuzzy integer; hazardous parts are known in advance; and demand is also known in advance and its quantity is deterministic.

Mathematical formulation of the multi-objective DLBP was first introduced in [7] as a deterministic model. Based on the main concepts of [7], a fuzzy extension of the problem is formulized considering fuzzy part removal times and fuzzy cycle time as follows:

$$\min f_1 = m \tag{1}$$

$$\min f_2 = \sqrt{\sum_{k=1}^{m} (\widetilde{c} - \widetilde{ST}_k)} \tag{2}$$

$$\min f_3 = \sum_{i=1}^{n} i \times h_{PS_i}, \quad h_{PS_i} = \begin{cases} 1 & \text{hazardous} \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

$$\min f_4 = \sum_{i=1}^{n} i \times d_{PS_i}, \quad d_{PS_i} \in N, \quad \forall PS_i \tag{4}$$

Subject to:

$$\sum_{k=1}^{m} x_{jk} = 1, \quad j = 1, \ldots, n \tag{5}$$

$$\left\lceil \frac{\sum_{i=1}^{n} t_i}{\widetilde{c}} \right\rceil \le n \tag{6}$$

$$\sum_{k=1}^{m} \widetilde{ST} \le \widetilde{c} \tag{7}$$

$$x_{ik} \le \sum_{k=1}^{m} x_{jk}, \quad \forall (i, j) \in IP \tag{8}$$

Objective functions; (1) aims to minimize the number of workstations, (2) balances the smoothness index ($\widetilde{SI}$) which shows the balance of workload distributed among the stations, (3) aims to remove hazardous component as early as possible whereas (4) aims to handle a high demand component as early as possible. Equation (5), guarantees that all tasks are assigned to exactly one workstation. Constraints; (6) guarantees that the number of work stations with a workload does not exceed the permitted number, (7) guarantees that the work content of workstation cannot exceed the cycle time, (8) guarantees that all the disassembly precedence relationship between parts should be satisfied.

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