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Technical paper

Type II robotic assembly line balancing problem: An evolution strategies algorithm for a multi-objective model

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ABSTRACT

In this paper a different type II robotic assembly line balancing problem (RALB-II) is considered. One of the two main differences with the existing literature is objective function which is a multi-objective one. The aim is to minimize the cycle time, robot setup costs and robot costs. The second difference is on the procedure proposed to solve the problem. In addition, a new mixed-integer linear programming model is developed. Since the problem is NP-hard, three versions of multi-objective evolution strategies (MOES) are employed. Numerical results show that the proposed hybrid MOES is more efficient.

1. Introduction

1.1. RALB problem description

The growing need for flexible production which is caused by competitive markets and customers demand for more variety, calls for flexible assembly systems in which, robots play an important role. A main configuration of robots in flexible systems, is the use of robotic assembly lines [1].

Assembly lines are flow-oriented production systems in the industrial production of high quantity, standardized commodities and low volume production of customized products [2]. An assembly robot can work with no weariness. The goals of robot implementation include a high productivity, a good quality of products, the manufacturing flexibility, the safety and a less demand for skilled labour [3].

The simple assembly line balancing (SALB) problem is the building block of this family of problems. SALB problems are those, in which, tasks are assigned to workstations such that precedence constraints between tasks or other constraints are met. Table 1 shows different versions of SALB problems presented by Scholl and Becker [2]. All the versions are NP-hard [4].

An assembly robot could be programmed to do different jobs, while another assembly robot may do same jobs with different efficiencies. Therefore, a wise allocation of robots to workstations is essential for a high performance of an assembly line.

A robotic assembly line balancing (RALB) problem is a problem of efficiently assigning tasks and allocating robots to workstations. There are two types of RALB problems, namely, type I and type II.

In type I robotic assembly line balancing (RALB-I) problems, with a given cycle time, the objective is to minimize the number of workstations or the cost of the assembly line. A type II robotic assembly line balancing (RALB-II) problem uses different robot types to perform assembly tasks. Each robot type has different processing time due to its capability and specialization.

This paper provides a new mixed-integer linear programming (MILP) model for an RALB-II problem. In the presented model, three objective functions, namely, the cycle time, the robot setup cost and the robot cost, are considered to be minimized, simultaneously. Because of the NP-hardness, a meta-heuristic algorithm, evolution strategies (ES), is utilized. For this purpose, three versions of multi-objective ES are employed for solving some test problems obtained from the literature. Four well-known performance measures are used to show that our proposed algorithm outperforms others.

1.2. Literature review

The model of Graves and Lamar [5] is on selecting workstations from a set of non-identical candidates and assigning tasks to the selected workstations, simultaneously. Their objective is to minimize the total cost of the system. Pinto et al. [6] work is about the design of an assembly line with identical and parallel machines.

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Table 1
Versions of SALB.

Versions of SALB	Cycle time (ct)	No. of workstations (K)	Objective
SALB-F	Given	Given	To establish whether or not a feasible line balance exists for a given combination of K and ct
SALB-1	Given	?	To minimize K
SALB-2	?	Given	To minimize ct
SALB-E	?	?	To minimize ct and K simultaneously considering their interrelationship

Khouja et al. [7] propose a two-stage methodology to design robotic assembly cells. Other works on RALB area are summarized in Table 2, which gives a brief and thorough view of previous studies.

Regarding evolution strategies, comprehensive studies have been done by Beyer and Schwefel [8], Bäck [9] and Costa and Oliveira [10]. Costa and Oliveira [11] provide an adaptive sharing ES for multi-objective optimization. For more details about multi-objective techniques, one can refer to [12,13,14].

1.3. Gap analysis

In practice, a decision maker may consider more than one objective, especially, in strategic plans such as robotic assembly line designs. Regardless of the robot cost, all previous studies considered only one objective. Considering the robot costs, this paper develops a new mixed-integer linear programming model with three well-known objective functions for the problem. In addition, it provides a new scheme of solution representation to deal with the problem via three versions of multi-objective evolution strategies.

The rest of this paper is organized as follows. In Section 2 the multi-objective type II robotic assembly line balancing problem is formulated. Section 3 is devoted to evolution strategies, encoding and decoding methods and the proposed search techniques. In Section 4, the problem is analyzed from the multi-objective point of view, and the procedure of dealing with that is discussed there. Numerical results of solving some available test problems are provided in Section 5. Finally, Section 6 concludes the paper.

2. Multi-objective type II RALB problem formulation

To produce a given product, a certain number of indivisible assembly tasks are needed, say J tasks. There are some precedence constraints which determine the order in which tasks could be performed. The assembly line has K serial workstations with a robot in each.

At first, this model aims to create an assembly line which does not exist. Let J assembly tasks and K workstations are given. The aim is to determine types of robots that should be bought such that the total cost of robots is minimized. Achieving an optimal decision needs three questions to be answered. How to assign tasks to workstations?, which type of robot has to be bought?, and how to allocate robots to workstations? Three objectives to be minimized are: cycle time, robot setup cost and robot cost.

The following assumptions considered in the model formulation are of those mentioned by Levitin et al. [1] and Gao et al. [3].

(1) The precedence relations among assembly tasks are known and invariable. This precedence is represented by a precedence graph.
(2) There are only r types of robot available ($r \geq 1$), but within each type, there is no limitation on the number of robots available, i.e., there are at least K robots of each type.
(3) The processing time of an assembly task depends on the allocated robot type.
(4) There is no limitation on assignment of an assembly task to any workstation other than precedence constraints.
(5) A single robot is allocated to each workstation.
(6) Each robot type necessarily does not have the ability to perform any assembly task. In a case that processing of an assembly task on a specified robot is not desired, the setup cost of the robot for that task is set infinity.
(7) Material handling, loading and unloading times are negligible, or are included in processing times.
(8) Due to time consuming nature of setups, robot setup times are considered.
(9) It is assumed that purchasing more than one robot of any type will have a discount, with a fixed and known rate related to that robot type.
(10) The purchase cost of robots is considered.
(11) The line is balanced for a single product.

Assumptions (2), (6), (8), (9), and (10) are of our own.
The following notations will be used.
Set of parameters:

J: number of assembly tasks with $j = 1, 2, \ldots, J$
K: number of workstations with $k = 1, 2, \ldots, K$
R: number of robot types with $r = 1, 2, \ldots, R$
$prc(j)$: set of immediate predecessors of task j with $h \in prc(j)$
t_{jr}: processing time of task j by robot type r

Table 2
Previous works on RALB.

Article	Cycle time (ct)	Model	Objective	Solution procedure
Nicosia et al. [7]	Given	Assigning tasks to non-identical workstations subject to precedence constraints.	To minimize the cost of the workstations	A dynamic programming algorithm
Rubinovitz and Bukchin [8]	Given	Formulate the RALB problem	To minimize the number of workstations	–
Rubinovitz et al. [9]	Given	Formulate the RALB problem	To minimize the number of workstations	A branch & bound algorithm
Bukchin and Tzur [10]	Given	Formulate the RALB problem	To minimize the total equipment cost	An exact and heuristic branch & bound
Levitin et al. [1]	?	A type II RALB problem	To assign tasks to workstations and to select the best fit robot type for each workstation such that cycle time is minimized	Two GA versions
Gao et al. [3]	?	A type II RALB problem	To minimize cycle time	A hybrid genetic algorithm