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An investigation on minimizing cycle time and total energy consumption in robotic assembly line systems

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ABSTRACT

Manufacturing industries give importance to the reduction of energy consumption due to the increase in energy cost and to create an eco-friendly environment. Assembly line is considered to be one of the cost intensive systems. Robots are recently being used to perform the assembly tasks instead of manual labor. There is a requirement of efficiently balancing the assembly line by allocating equal amount of work to workstations and assignment of best fit robot to perform the tasks allocated to those workstations. The authors could not find any research on optimizing cycle time and total energy consumption concurrently in robotic assembly line systems to date. The objective of this paper is to propose models with dual focus on time and energy to minimize the cycle time and total energy consumption simultaneously, one model (time based model) with the primary focus to optimize cycle time and the other model (energy based model) with the primary focus to optimize total energy consumption. Particle swarm optimization is used as the optimization tool to solve this problem. Computational experiments are conducted on the proposed models using the benchmark problems available in the open literature and the results are presented. The two models proposed in this paper are very well applicable to automobile body shop with robot based lines. The models proposed have a significant managerial implication in real assembly line systems. Depending upon the priorities of the management, primary focus on reducing either cycle time or total energy consumption, suitable models could be selected. The proposed models are useful to reduce the total energy consumption and cycle time in robotic assembly lines. It is observed that the computation time for the time based model is less compared to energy based model.

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1. Introduction

Energy is one of the most important vital resources in manufacturing scenario. Importance of energy efficiency has been realized in the recent years and stressed more than ever (Liu et al., 2014). Energy consumption is considered to be critical cost element in a manufacturing enterprise (Kilian, 2008). One of the major goal of many modern manufacturers in the recent years is to decrease the cost of production by any possible means while satisfying the environmental regulations and ensuring quality, and customer (Güngör and Gupta, 1999). Electricity is one of the important forms of energy which is used in a manufacturing sector. Production of electricity is a highly polluted process. Due to the consumption of electricity, amount of carbon dioxide emission generated would be around 20% (Dai et al., 2013). Thus manufacturing companies are required to reduce the energy consumption and become environment friendly. Due to the depletion of reserves of energy commodities such as petroleum and other fossils fuels and growing concern over global warming, there has been a growing interests for minimization of energy consumption by the industries (Mouzon and Yildirim, 2008).

Due to rise in energy price and increased demand for environmental compliant efficient energy management system and sustainable energy have become important factors for business competitive advantages. Reduced usage of energy helps the

Acronyms: ALB, Assembly Line Balancing; sALB, Simple Assembly Line Balancing; RALB, Robotic Assembly Line Balancing; NP, Non Polynomial; ACO, Ant Colony Optimization; EPC, Electric Power Cost; TOU, Time of use; FFS, Flexible Flowshop Scheduling; GA, Genetic Algorithm; PSO, Particle Swarm Optimization.

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industries to save cost and become more competitive. This is a key factor for promoting green and sustainable practices (Ngai et al., 2013). In a manufacturing industry, assembly line is considered to be one of the cost intensive processes. Using an energy efficient manufacturing system the energy consumption can be reduced (Chryssolouris, 2005).

Fysikopoulos et al. (2012) indicated that for manufacturing a car (Press, body, paint and assembly shops) could consume energy up to 700 kwh/vehicle. According to them, this energy cost is about 9–12% of the total manufacturing cost and a 20% reduction in energy cost shall be about 2–2.4% reduction in the final manufacturing cost. Extensive efforts are being under taken to improve the efficiency and cost effectiveness of assembly systems due to the economic importance of assembly as a manufacturing process (Sanderson et al., 1990).

Assembly line requires tedious, repetitive tasks which wearisome and some are dangerous for workers. Salveson (1955) mathematically formulated the model for Assembly Line Balancing (ALB) problem. Assembly Line Balancing (ALB) or simple Line Balancing (LB) problems mainly deals with assigning tasks to workstations in such a way that the assignment is in a balanced manner. While assigning the tasks to the workstations the precedence constraints are to be satisfied. Simple assembly line balancing (sALB) problems are of two types: simple ALB-I (sALB-I) and simple ALB-II (sALB-II). sALB-I mainly aims at assignment of tasks to workstations with the aim of minimizing the number of workstation whereas, sALB-II problem aims at minimizing the cycle time by assigning the tasks to the given set of workstations (Scholl, 1999).

Robots are being used extensively in assembly lines to perform the tasks and these assembly lines are called robotic assembly lines (Gao et al., 2009). The robots are programmed to perform different types of tasks and it can be used to work 24 hrs without worries of fatigue. Different types of robots are available in market to do the same task with different capabilities and efficiencies. Therefore, there is a requirement of judicious allocation of robots to workstations with certain specific objective. A typical robotic assembly line balancing (RALB) problem is to assign tasks to workstations and to allocate robot for each station in order to improve the productivity (Levitin et al., 2006).

Two types of RALB problems are addressed in the literature as type-I and type-II. Type I RALB problem aims at minimizing the number of workstations for a given cycle time of the assembly line. The type-II RALB problem aims at assigning tasks to workstations and to select the best fit robot for each workstation in such a way that cycle time is minimized (Gao et al., 2009). RALB problem is first formulated by Rubinovitz and Bukchin (1991) in which equal amount of tasks are allocated to the workstations in the assembly line and the best available robot to perform the tasks are assigned to the workstations with an objective of minimizing the number of workstations for a given cycle time.

Later, type-II RALB problem is developed with an aim of assigning tasks to work stations and select the best fit robot type for each workstation such that cycle time is minimized (Gao et al., 2009; Levitin et al., 2006). Yoosefelahi et al. (2012) formulated a multi-objective mixed integer linear programming model for type-II RALB problem aims to minimize the cycle time, robot setup costs and robot costs.

Literature on assembly line balancing problems shows that the key objectives evaluated are cost, time, and quality. However, the research on minimizing energy consumption in manufacturing systems has been rather limited (Dai et al., 2013). In case of RALB, most of the researchers considered only type-I and type-II robotic assembly line balancing problems for assigning tasks and allocating robots to workstations. Very limited researches related to assembly line problems in the context of minimizing energy consumption are available and few of them are briefly discussed below.

Fysikopoulos et al. (2012) showed that by modeling an assembly line in advance and by including energy considerations, one can possibly save energy and cost. An empirical study of the energy consumption of an automotive assembly line, under various scenarios and demand profiles is presented by them. (Luo et al., 2013) proposed a multi-objective ant colony optimization meta-heuristic to optimize not only production efficiency but also electric power cost (EPC) with the presence of time-of-use (TOU) electricity prices. Dai et al. (2013) proposed an energy-efficient model for flexible flow shop scheduling (FFS). A mathematical model for an FFS problem which is based on an energy-efficient mechanism is described by them. Due to NP-hard nature of the problem, an improved genetic-simulated annealing algorithm is adopted by them to make a significant trade-off between the make-span and the total energy consumption to implement a feasible scheduling.

Mouzon et al. (2007) developed several algorithms and a multi-objective mathematical programming model for investigating a problem of scheduling jobs on a single CNC machine in order to reduce energy consumption and completion time.

Shrouf et al. (2013) proposed a mathematical model to minimize the energy consumption cost for a single machine production system considering variable energy prices during a day. They proposed a genetic algorithm (GA) to obtain 'near' optimal solutions. They evaluated the performance of the proposed GA with an analytical solution generated. He et al. (2012) proposed a modeling method of task oriented energy consumption for machining manufacturing system by incorporating an event graph methodology. They solved the model using SIMULINK simulation environment.

Assembly line balancing problem belongs to the category of NP-hard (Gutjahr and Nemhauser, 1964). In the literature, researchers use optimization or simulation models to solve assembly line balancing problems. Researchers in the recent past have suggested that both optimum-seeking and heuristic algorithms can be used to solve single-model assembly line balancing problems. Exact methods guarantee an optimum solution, whereas heuristic methods only attempt to yield a good, but not necessarily optimum solution. But, the time taken by an exact method to find an optimum solution for NP-hard problem will be much greater than the time taken by any heuristic method. Hence, heuristic methods are used to solve real optimization problems which are generally complex (Martí and Reinelt, 2011).

There are limited literature available in both the categories. The available literature are presented in this section.

Rubinovitz et al. (1993) first introduced a branch and bound algorithm for RALB type I problem. An exact heuristic branch and bound algorithm is used to obtain optimal solutions for small and medium-sized ALB problem instances (Bukchin and Tzur, 2000). Rashid et al. (2012) presented a list of heuristic algorithms applied to ALB problem. According to them only limited heuristic algorithms are applied to RALB problems. So far, genetic algorithm (Levitin et al., 2006), hybrid genetic algorithm (Gao et al., 2009) and particle swarm optimization (Mukund Nilakantan and Ponnambalam, 2012) have been used to solve RALB problems to optimize the cycle time.

Daoud et al. (2014) proposed several evolutionary algorithms and a discrete event simulation model to solve robotic assembly line balancing problem and they considered an automated packaging line dedicated for dairy food products as the case study.

Villarreal and Alanis (2011) presented a simulation approach that could improve the efforts during the redesign of a traditional assembly line system applicable to an assembly system in Mexico.

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