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# A modified Genetic Algorithm approach to minimize total weighted tardiness with stochastic rework and reprocessing times

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ABSTRACT

Scheduling challenges are typical with electronics manufacturing services (EMS) providers. The rework and reprocessing of failed electronics components consume more time in the production line, causing jobs to miss their due dates. A mathematical model and a Modified Shortest Total Estimated Processing Time (MSTEPT) Algorithm to minimize the Total Weighted Tardiness (TWT) are proposed in this research. This research then develops a novel modified Genetic Algorithm approach to solve the scheduling problem with stochastic rework and reprocessing time. While the Genetic Algorithm as a methodology to solve scheduling problems has been developed in earlier research articles, the existing set of genes in the chromosomes of a regular Genetic Algorithm would not be able of handle jobs waiting to undergo reprocessing. The modified Genetic Algorithm in this research introduces the concept of *priority genes*, specifically encoded to handle jobs waiting to be reprocessed after they have been reworked. Experimental results indicate that the proposed modified GA outperforms the best of different commonly used dispatch rules, in terms of solution quality. For small-to-medium-sized job shops, the proposed algorithm outperforms optimal results from CPLEX® optimal solver, as well as those from the MSTEPT algorithm.

## 1. Introduction

Job failures are typical in the electronics manufacturing process and could be at the printed circuit board (PCB) assembly level and during final product assembly processes. Solder bridging, voiding, missing components or wrong orientation and electrical shorts or opens are some of the common defects at the PCB level while improper alignment and connection of PCBs, mechanical defects and other quality related issues occur at the final product assembly level (Lee, 2002). When assembly defects are identified at the testing phase or during a visual inspection, the products are reworked to restore them to original operating conditions. *Off-line* rework can be performed on a separate rework machine but would require the jobs to return to the same machine for reprocessing, such as retesting or visual inspection. *In-line* rework and reprocessing are performed on the same machine.

When jobs return for rework or reprocessing, they need to spend additional time waiting in the queue, as well as more set-up time, such as setting up the right pick-and-place program or the right reflow profile recipe. The EMS providers generally deliver services to multiple customers for various product types, which could result in increased opportunities for defects. That delays the job completion process, resulting in job tardiness. Special attention needs to be given to those jobs that have a higher chance of failure, leading to increased tardiness. However, in most cases, the jobs are only processed based on their due dates, job priority or weights, or some other criteria such as FIFO (First In First Out). Even though several researchers have studied the scheduling problem, there is limited research pertaining to electronics manufacturing scheduling with stochastic rework and reprocessing times.

Therefore, the objective of this research is to develop a methodology to minimize the total weighted tardiness, considering rework and reprocessing times based on their probabilities. In this regard, a mixed integer programming (MIP) model to solve the scheduling problem optimally is proposed. Then, a heuristic algorithm is discussed. A modified Genetic Algorithm, as a meta-heuristic approach, is also proposed in this research to schedule jobs. A generic Genetic Algorithm is not capable of handling the jobs that return to the same machine for in-line rework or reprocessing. The modified algorithm introduces priority genes to accommodate and process these jobs waiting for in-line rework or reprocessing. Moreover, this algorithm establishes that jobs in these priority genes must be processed first before starting to process a new job. The proposed algorithms have been experimented with a high

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product mix setup by varying the job-instance size, to evaluate the effectiveness of the algorithm for a single-machine and multi-machine setup. There are several assumptions made in this research. It is assumed that in-line and off-line rework probabilities and reprocessing time distribution for all the jobs are available. Typically, the EMS manufacturing system keeps track of rework and reprocess rates for every unit. Also, it is assumed that failure and rework of any job at any operation occurs only once at the maximum and a failed job returns to original operating conditions if the rework has been performed.

The remainder of this paper is organized as follows. A brief review of the literature is presented in Section 2. An integer programming model to minimize the TWT is explained in Section 3. The MSTEPT algorithm is outlined in Section 4. The Modified Genetic Algorithm and the selection of its different parameters are explained in Section 5. Experimental results and analyses are discussed in Section 6. Finally, conclusions, limitations, and future work are outlined in Section 7.

## 2. Literature review

Scheduling problems are computationally intensive as the number of solutions could grow exponentially with the job-instance size (Hoitomt, Luh, & Pattipati, 1993; Lenstra, Kan, & Brucker, 1977). The computational complexity in scheduling has been discussed in several research articles (Garey, Johnson, & Sethy, 1976; Gonzalez & Sahni, 1978; Manne, 1960). The challenging nature of the scheduling problem has led to a number of research articles in this area, with different methods to obtain optimal to near-optimal solutions. The use of priority rules can be termed as one of the earliest research in this domain, which resulted in influencing the scheduling process (Conway, Johnson, & Maxwell, 1960). Comparison between several such priority rules showed the superiority of the Shortest Processing Time (SPT) rule, which has become the standard rule for comparison (Conway, 1965).

Several meta-heuristic methods have been developed in recent years. One research developed a Variable Neighborhood Search (VNS) algorithm and Multiple Ant Colony Optimization (MACO) for a multi-objective optimization to minimize makespan and total tardiness (Liang, Hsiao, & Tien, 2013). The VNS algorithm performed better than other meta-heuristic methods tested, in terms of solution quality and computation time. A recent research used reinforcement learning (RL) technique to determine proper parameters for the VNS to optimize the mean flow time of jobs in a dynamic job shop with random job arrivals and machine breakdowns (Shahrabi, Amin, & Mahootchi, 2017). Another research developed a path-relinking algorithm by using the Greedy Randomized Adaptive Search Procedures (GRASP) to provide its initial solutions for $x$ and $y$ (Bakhtar, Jazayeriy, & Valinataj, 2015). The GRASP approach first linked $x$ to $y$ to get a best solution $x_{PR}$, then did a local search to improve it and obtain $x_{LS}$, and finally evaluated these solutions to move to the next iteration's initial solution. The authors used this approach to minimize the makespan.

The focus of the current research is on scheduling jobs effectively in an electronics manufacturing system. Of the different scheduling-based researches in electronics manufacturing, one focused on minimizing component switching in a component interchange machine (Maimon & Braha, 1998), while another aimed at optimizing the allocation of feeders to slots in pick-and-place machines (Kulak, Yilmaz, & Gunther, 2007; Magazine & Polak, 2003). A series of studies to minimize the makespan in electronics manufacturing facilities involving batch processing test operations have been conducted (Damodaran & Chang, 2008; Damodaran & Srihari, 2004; Damodaran, Diyadawagamage, Ghrayeb, & Vélez-Gallego, 2012). Meta-heuristic methods help achieve near-optimal solutions in relative faster times. Meta-heuristic approaches such as Genetic Algorithm (GA) and Ant Colony Optimization (ACO) have been employed for effective scheduling in PCB manufacturing (Pradhan & Lam, 2007). Another meta-heuristic approach, Simulated Annealing (SA), has been used in a flow shop to minimize the makespan (Manjeshwar, Damodaran, & Srihari, 2009).

The literature review suggests that several studies in the electronics manufacturing domain have been conducted to minimize the makespan. A key indicator to monitor the product delivery due date conformance is weighted tardiness, which leverages a company's good will with customers (Valente & Alves, 2008). The objective of minimizing the TWT in the electronics manufacturing domain remains a gap in the literature. This could be because the TWT is one of the most complex objective functions to minimize in the job shop scheduling problem (JSP) (Pinedo, 2008). Research suggests the NP-hard nature of even the single machine TWT minimization problem (Du & Leung, 1990). Hence, it is understandable that several studies have developed heuristic algorithms to minimize the TWT and compared their performance against dispatch rules such as Earliest Due Date (EDD), Weighted EDD, SPT, and Weighted SPT (Mason, Fowler, & Carlyle, 2002, 2005; Neammanee & Reodecha, 2009; Zhou, Cheung, & Leung, 2009).

Research done during recent years could be termed as problem-based or methodology-based. Problem-based research examines the types of scheduling problems and constraints involved (the type of job shop or flow shop, the objective function optimized), and methodology-based research looks at the new techniques, mostly heuristic, being developed for effective scheduling. Even though different methodologies have been developed to address several problem types, there has been little research that has addressed jobs that fail, undergo rework, and get reprocessed. System load balancing to improve throughput in a photolithographic area with an on-line rework strategy, by developing a dispatch rule, has been studied (Sha, Hsu, Che, & Chen, 2006). The throughput is maximized by determining whether a mother lot should wait for the defective child lot after rework. If the rework time for the child lot is lesser than the waiting time of the mother lot at the subsequent step, the child lot is considered a hot lot and reworked immediately, to reunite with the mother lot. However, Sha et al. did not vary rework time based on the type of job as it will be a constant equal to the time to rework a wafer at the rework process.

Another study aimed to determine the sequence of batch sizes to minimize makespan for a single product line (Gribkovskaia, Kovaleva, & Werner, 2010). The product was manufactured in two stages - a main facility for original production and a second facility for remanufacturing or reworking the defective units. The two stages or facilities are considered as two machines (machine *1* and machine *2*). Quality inspection (on-line or off-line) in batches in machine *1* determines whether a unit is defective and needs to be reworked. The fraction of defective units is considered the same in any given batch, and consistent with several literature. A linear programming approach is provided for the problem, and the problem is reduced to $K$ linear programming problems, where $K$ is the upper bound on the number of batches. The research also developed an $O(\log K)$ time solution approach. However, being a single product line, its model assumed rework time to be identical for all units. Additionally, the rework stage was the second stage in a two-stage model, and units from this stage were good quality units.

In a different research involving a flow shop with re-entrant jobs, the weighted tardiness and makespan were minimized (Lee, Lin, Ho, & Wu, 2011). However, that study did not consider rework and reprocessing time and did not develop any dispatching rules or algorithms to efficiently handle re-entrant jobs.

A parallel machine scheduling problem adapted rework and reprocessing times to schedule jobs to parallel and available machines such that the chances for failure were reduced (Kang & Shin, 2010; Kang, Kim, & Shin, 2010). The algorithm methodology involved indirectly perturbing one of the problem data vectors (processing times, due dates, setup times or rework probabilities). EDD and SPT were among the dispatching algorithms used by the authors to compare the performance of their methodology. However, that research did not consider any preemptive rule in their model. As there were multiple machines to process, the issues arising when having only one machine remain unaddressed. A similar research with parallel machines