A Framework to Minimize Total Energy Consumption and Total Tardiness on a Single Machine

Gilles C. Mouzon*, Mehmet B. Yildirim

Department of Industrial and Manufacturing Engineering, College of Engineering

Abstract. A great amount of energy is wasted in industry by machines which stay idle due to underutilization. A way to avoid consuming the wasted energy is to incorporate energy consumption into consideration while making the scheduling decisions which optimize objectives such as total tardiness. In this paper, a framework to solve a multiobjective optimization that minimizes total energy consumption and total tardiness is proposed. After modeling the multiobjective problem, a greedy randomized adaptive search metaheuristic is proposed to obtain an approximate pareto front (non-dominated solutions). Next, Analytic Hierarchal Process is utilized to determine the "best" alternative.

1. Introduction

The increase in price and demand for petroleum and other fossil fuels, together with the reduction in reserves of energy commodities, and the growing concern over global warming, have resulted in greater efforts toward the minimization of energy consumption. In USA, the manufacturing sector consumes about one third of the energy usage and contributes about 28% of greenhouse gas emissions. In order to produce one kilowatt-hour of electricity, two pounds of carbon dioxide is released into the atmosphere, thus contributing to the global warming [1]. As a result, research in minimization of energy in a manufacturing environment using operational methods might provide significant benefits in both reduced costs and environmental impacts. The proposed framework can be applied to any production setting and may save significant amount of energy while keeping a good service level in terms of scheduling and energy consumption objectives. Also, using this algorithm, the industry may have a smaller signature on environment, thus, may lead to more environmentally friendly production planning.

In order to ensure energy efficient production planning, Mouzon et al. [2] propose dispatching rules to minimize energy consumption as well as maximum completion time for a single machine dynamic scheduling problem. The scheduling objective that is considered is the total tardiness (lateness of the tasks) objective which is a widely used measure of performance in manufacturing environment. The total tardiness objective can be defined as minimizing the sum over all jobs of max (c_j - d_j, 0), where d_j is the due date of job j and c_j is completion time of job j. The total tardiness is the sum of all jobs' lateness over the scheduling horizon. If the job is on time or early, the tardiness associated with the job is zero. It is also assumed that jobs are processed without preemption. Furthermore, the jobs may have non-zero release dates (i.e., r_j ≥ 0). Note that total tardiness problem with non-zero release dates on a single machine is considered NP-hard problem [3]. In other words, there is no algorithm to solve this problem in polynomial time. As a result our problem which has total tardiness problem as one of the objectives is also NP-hard.

The method used in this paper to solve the scheduling problem is Greedy Randomized Adaptive Search Procedure (GRASP). An extensive review of the GRASP heuristic can be found in [4]. The goal of a heuristic in multiobjective optimization is to obtain an estimation of the pareto optimal front which represents the non-dominated solutions to the problem.

In this paper, a framework to obtain a set of efficient solutions which minimizes the total energy consumption and total tardiness of jobs on a single machine is proposed. The framework utilizes a metaheuristic to determine a set of non-dominated solutions and then analytical hierarchal process to select the most suitable solution to be implemented on the shop floor.

2. Model and Case Study

The Multiobjective Total Energy Total Tardiness (MOTETT) optimization problem can be defined as in figure 1. The parameters are the processing time of a job j (p_j), the release date of a job j (r_j) and the due date of a job j (d_j). Also, the idle power
consumption of the machine (Power_idle), the processing power of the machine (Power_processing), the energy used for a setup (Energy_setup) and the setup time (S) are known. The variable of interest is the completion time of each job \( j \) \( c_j \). The energy consumption objective (equation 1 is the sum of the total idle energy (i.e., the energy consumed when the machine is not processing any job) and total setup energy (i.e., the energy necessary to turn on and off the machine). Note that the total processing energy (\( \text{Power}_{\text{processing}} \sum p_j \)) is not included in the optimization problem, since it is a fixed constant regardless of the sequence. The second objective is the total tardiness objective (equation 2). In the mathematical formulation, equation 3 states that a job cannot be processed before it is released. Equation 4 ensures that two jobs cannot be processed at the same time. Finally, equation 5 states that if a job \( j \) precedes a job \( k \) and if a setup will be performed (since the idle duration is longer than the breakeven duration \( T_B \) \( \text{max}(S, \text{Energy}_{\text{setup}} \text{Power}_{\text{idle}}) \)), then \( y_{jk} \) is equal to the corresponding idle energy minus the setup energy.

\[
\begin{align*}
\min \ ( & \max c_j - \min c_j) \times \text{Power}_{\text{idle}} - \sum_{j=1}^{n} \sum_{t \in T_j} p_j \\
\min \ & \sum_{j=1}^{n} \max(c_j - d_j, 0) \\
\text{such that} \ & c_j \geq p_i \quad \forall j = 1 \ldots n \\
\text{and} \ & c_k \geq p_k \quad \forall k = 1 \ldots n \\
\text{and} \ & c_j \geq c_k \quad \forall j \neq k \\
\text{and} \ & c_k \geq \min(c_j - d_j) \quad \forall j \neq k \\
\text{then} \ & y_{jk} = (c_k - d_k) \times \text{Power}_{\text{idle}} - \text{Energy}_{\text{setup}} \\
\text{with} \ & c_i \geq 0 \quad \forall i, j = 1 \ldots n \\
\end{align*}
\]

Fig. 1. Multi-objectives optimization problem

Greedy Randomized Adaptive Search Procedure (GRASP), is an iterative metaheuristic that has two phases. First, a solution is created in the construction phase, and then the neighborhood of this solution is locally searched in order to obtain a better solution. It is very important to define a “suitable” neighborhood in the local search phase to converge to a near-optimal solution quickly.

In order to solve MOTETT, we adapt the single objective GRASP algorithm to the multiobjective case. The multiobjective GRASP to minimize total energy total tardiness (GRASP-TETT) considers a pareto front to evaluate the objectives instead of a single objective function value.

GRASP-TETT algorithm provides an approximate pareto front. To identify the “best” alternative among the non-dominated solutions on the pareto front, the decision maker can utilize his/her own preferences which may be used as an input to Analytic Hierarchy Process (AHP) [5]. AHP can choose the best alternative among a set of non-dominated solutions. The objective is to maximize the overall purpose (the top level). The decision maker has to structure the problem in a hierarchy of criteria and sub-criteria to maximize the overall purpose (the top level). He also has to provide pairwise comparison of the criteria to determine the value of the weight that will permit to evaluate each alternative. In addition to total tardiness and total energy consumption criteria, we can add criteria such as maximum tardiness, total number of setups or maximum completion time.

Figure 2 illustrates the pareto front obtained using the GRASP algorithm on a 50 jobs problem and the “best alternative” according to AHP is highlighted.