A hybrid multi-objective GA for simultaneous scheduling of machines and AGVs in FMS

Abstract A carefully designed and efficiently managed material handling system plays an important role in planning and operation of a flexible manufacturing system. Most of the researchers have addressed machine and vehicle scheduling as two independent problems and most of the research has been emphasized only on single objective optimization. Multiobjective problems in scheduling with conflicting objectives are more complex and combinatorial in nature and hardly have a unique solution. This paper addresses multiobjective scheduling problems in a flexible manufacturing environment using evolutionary algorithms. In this paper the authors made an attempt to consider simultaneously the machine and vehicle scheduling aspects in an FMS and addressed the combined problem for the minimization of makespan, mean flow time and mean tardiness objectives.

Keywords Automated guided vehicle · Evolutionary algorithms · Multiobjective · Non-dominated solutions · Scheduling

1 Introduction

In the present day automated manufacturing environment, flexible manufacturing systems (FMS) are agile and provide wide flexibility. FMS are well suited for simultaneous production of a wide variety of part types in low volumes. FMS is a complex system consisting of elements like workstations, automated storage and retrieval systems, and material handling devices such as robots and AGVs [1]. The FMS elements can operate in an asynchronous manner and the scheduling problems are more complex. Moreover the components are highly interrelated and in addition contain multiple part types, and alternative routings etc. FMS performance can be increased by better co-ordination and scheduling of production machines and material handling equipment [2].

Scheduling is concerned with the allocation of limited resources to tasks overtime and is a decision making process that links the operations, time, cost and overall objectives of the company. Scheduling of machines, other resources such as vehicles, personnel, tools etc. has been done with a certain objective, to be either minimized or maximized. Some of these objectives include minimization of makespan, tardiness, earliness, in process inventory etc. [3]. Typically parts in a manufacturing system visit different machines for different operations, and they thus generate demand for the material handling devices. Scheduling of the material handling system in FMS has equal importance as of machines and is to be considered together for the actual evaluation of cycle times. Automated guided vehicles (AGVs) are widely used in flexible manufacturing systems due to their flexibility and compatibility [4]. AGVs can be integrated with the computer controlled production and storage equipment in the shop floor and the entire shop floor operations can be controlled through a computer system.

Most of the real world-scheduling problems involve simultaneous optimization of multiple objectives. Dealing with multiple objectives has received much attention over the last few years, where as scheduling is still dominated by the unrealistic single objective approach. The main goal of a multi-objective optimization problem is to obtain a set of Pareto optimal solutions that satisfy the constraints [5]. Genetic algorithms (GA) are widely used in the last two decades to address the multi-criteria decision problems. Genetic algorithms are non-deterministic stochastic search methods that utilize the theories of evolution and natural selection to solve a problem within a complex solution space [6]. In recent years, new algorithms such as non-sorting genetic algorithm–II (NSGA-II) and strength Pareto evolutionary algorithm–2 (SPEA-2) have been developed and are now widely used to address the multi-objective problems.

In this paper the authors have made an attempt to address simultaneously both the machine and vehicle scheduling in
the flexible manufacturing environment for minimization of makespan, mean flow time and mean tardiness using non-dominated sorting genetic algorithm NSGA-II. The efficacy of the method for the said simultaneous scheduling problem has been thoroughly tested. The following sections describe the development and application of GAs for simultaneous scheduling problems with illustrated examples.

### 2 Literature review

Most of the researchers have addressed the machine and vehicle scheduling as two independent problems. However, only a few researchers have emphasized the importance of simultaneous scheduling of machines and vehicles. A deterministic off-line scheduling model was presented by Raman et al. [7]. They formulated the problem as an integer programming problem and proposed a solution procedure based on the concepts of project scheduling under resource constraints. Their assumption was that the vehicles always return to the load/unload station after transferring a load which reduces the flexibility of the AGV and influence the overall schedule length. Blazewicz et al. [1] has considered an FMS with parallel identical machines arranged in a loop. They addressed the simultaneous scheduling problem using a dynamic programming approach. Sabuncuoglu and Hommertzheim [4] has tested the different machine and AGV scheduling rules in FMS against the mean flow time criterion. Another off-line model for simultaneous scheduling of machines and material handling system in an FMS for the makespan minimization is presented by Bilge and Ulusoy [8]. The problem was formulated as a non-linear mixed integer-programming model and was addressed using the sliding time window approach. Ulusoy et al. [9] has addressed the same problem using genetic algorithms. In their approach the chromosome represents both the operation number and AGV assignment which requires development of special genetic operators. Anwar and Nagi [2] addressed the simultaneous scheduling of material handling operations in a trip-based material handling system and machines in JIT environment. Abdelmaguid et al. [10] has presented a new hybrid genetic algorithm for the simultaneous scheduling problem for the makespan minimization objective. The hybrid GA is composed of GA and a heuristic. The GA is used to address the first part of the problem that is theoretically similar to the job shop scheduling problem and the vehicle assignment is handled by a heuristic called vehicle assignment algorithm (VAA). Lacomme et al. [11] has addressed the simultaneous job input sequence and vehicle dispatching for a single AGV system. They solved the problem using the branch and bound technique coupled with a discrete event simulation model.

Multi-objective optimization has been a subject of interest to researchers of various backgrounds since 1970 and genetic algorithms have received considerable attention as a novel approach to the multiobjective optimization problems. Schaffer [12] has presented a multi-modal EA called vector evaluated genetic algorithm (VEGA), which carries out selection for each objective separately. An approach based on the weighted sum scalarization was introduced by Hajela and Lin [13] to search for multiple solutions in parallel. Horn et al. [14] proposed the niched Pareto genetic algorithm that combines tournament selection and the concept of Pareto dominance. Fonseca and Fleming [15] proposed a multi-objective genetic algorithm (MOGA). Their approach consists of a scheme in which the rank of an individual corresponds to the number of individuals by which it is dominated.

Based on Goldberg’s suggestions Srinivas and Deb [16] developed an approach called non-dominated sorting genetic algorithm (NSGA). The non-dominated solutions of a front are assigned the same dummy fitness value and are shared with their dummy fitness values and ignored in the further classification process. Finally, the dummy fitness is set to a value less than the smallest shared fitness value in the current non-dominated front. Then the next front is extracted and the process is repeated until all the individuals in the population are classified. Zitzler and Thiele [17] has proposed the strength Pareto evolutionary algorithm (SPEA). They maintained an external archive which stores all the non-dominated solutions found at every generation from the beginning. The archive solutions are allowed to participate in the genetic operations which lead to the quick convergence of the algorithm. Knowles and Corne [18] developed an approach called Pareto archived evolution strategy (PAES) that incorporates elitism. In their approach non dominance comparison was made between a parent and the child. Deb et al. [19] proposed NSGA-II and showed that it out performs SPEA and PAES methods for certain test problems. Zitzler et al. [20] developed an approach called SPEA2 where the potential weaknesses of its predecessor SPEA are eliminated and an improved fitness assignment scheme is used.

### 3 Multi-objective optimization

If more than one criterion is to be treated simultaneously, then it is a multi-objective optimization problem. Most of real world decision problems involve multiple and conflicting objectives that need to be tackled while respecting the various constraints [21]. In multi-objective problems, there may not exist one solution, which is best with respect to all objectives. There exists a set of solutions, which are better than the other solutions in the search space when all the objectives are considered but are inferior to the solutions in one or more objectives and these solutions are called non-dominated solutions [22] and are shown in Fig. 1.

**Problem formulation** For a given FMS environment with machines arranged in a typical layout, the set of jobs to be processed and the vehicles, generate an optimum machine and vehicle schedule that is best with respect to the makespan, mean flow time and mean tardiness.

**FMS environment** A load/unload station with sufficient input/output buffer space serves as the distribution/collection centre for the parts. Flow path layout and the number