Simultaneous workload balancing and travel time minimization of automatic guided vehicles

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Abstract. This paper presents the application of a novel modified memetic particle swarm optimization algorithm (MMPSO) for simultaneous workload balancing and travel time minimization of automatic guided vehicles (AGVs) in the flexible manufacturing system (FMS). Three FMS layouts consisting of 5, 7 and 9 work centers are considered respectively for the simultaneous scheduling of AGVs in the FMS layouts. The resulting yield from the MMPSO algorithm is compared with the resulting yield of other implemented methods. From the results, it is observed that the application of the MMPSO algorithm outperforms the other applied algorithms from the literature. It was also observed that by the application of MMPSO algorithm a balanced exploration and exploitation of solutions can be achieved for the simultaneous scheduling of AGVs in the FMS.

1. Introduction

The flexible manufacturing systems (FMS) are highly automatic manufacturing systems which are extensively used for the production of mid variety and mid volume parts. In general, the FMS consists of highly accurate and precise work centers, inspection centers and material handling systems which are controlled by computer programs automatically. The automatic guided vehicles (AGVs) are commonly applied for material handling activities in the FMS. The AGVs transfer the in-process parts to different work centers while moving on the flow-path configuration in the FMS. It is commonly observed that in the real-time manufacturing conditions the dynamic variations in the variables of the system causes the scheduling of material handling operations to be highly complicated and difficult. The efficient material handling operations performed by the AGVs can significantly increase the throughput of the FMS. In order to carry out sustainable and efficient material handling operations, the AGVs workload should be balanced and also AGVs travel time must be minimized simultaneously in the FMS layout [5]. In this paper, the modified memetic particle swarm optimization algorithm (MMPSO) is used for the simultaneous workload balancing and travel time minimization of AGVs in three sizes of the FMS layout. Thereafter the output result of MMPSO algorithm is compared with the output results of different algorithms as observed from the literature.
2. Literature review

In the FMS, the scheduling system assigns different part transfer assignments to different locations in the FMS without any loss of time by the moving AGVs. According to the developing schedule, the AGVs pick and drop the parts at the required location. Efficient AGVs schedule offers optimum utilization of the FMS resources, increase the FMS throughput and also minimize the travel time of AGVs in the FMS [1]. Improper scheduling effects of AGVs in FMS were reported by [20] namely Collisions – if one or more than one AGV moves on the same track at the same time then a collision between AGVs are observed.

Congestions – If too many AGVs move on the same track than congestion between AGVs occurs and lowers down the FMS throughput.

Live-locks – While crossing intersections sometimes the AGVs is given a higher priority in comparison to other AGVs moving on the flow path of FMS causing live-locks in the system.

Dead-locks – If the number of AGVs waits for the release of work part on the same flow path, then the situation of deadlock among the AGVs arises in the FMS.

In order to avoid aforementioned improper scheduling effects, minimize AGVs travel time, and workload balancing of AGVs so as to maximize profits from the manufacturing operations, the multi-objective scheduling for AGVs has to be carried out. The nature-inspired heuristic algorithm can be further applied for the optimized schedules of AGVs in the FMS. [18] Compared the overall throughput of unit load AGVs and multi-load AGVs operating under different dispatching rules in the FMS. The shortest route out of the available routes was investigated by [16]. In order to find the shortest route an algorithm was applied by the authors and same was validated by testing on benchmark problems found in the literature. The real-time manufacturing scenario was analyzed by [24] and authors performed online scheduling of AGVs after applying time-window constraints. It was observed by the authors that the application of time window constraint develops a new service request with every new assignment schedule of AGVs. [17] Carried out a dynamic scheduling of AGVs in the FMS. Authors applied a beam search algorithm for the dynamic scheduling of AGVs and authors observed that the length of the planning horizon plays a significant role in the dynamic scheduling of AGVs. The beam search algorithm found to be an appropriate alternative for scheduling cases with longer planning horizons and also requiring frequent rescheduling of AGVs. [19] Also published their work on similar research paths. Simultaneous scheduling of work centers and AGVs was carried out by [14]. Authors introduced an adaptive genetic algorithm (AGA) and minimized the penalty cost as well as work center idle time simultaneously. The superiority of AGA was validated by comparing AGA results with the results of the conventional genetic algorithm. [15] Proposed some regression-based meta-models for the scheduling of AGVs in the FMS and also applied seven dispatching rules with discrete event simulation to simulate the developed models. Authors evaluated performance factors namely mean tardiness, the percentage of tardy and mean flow time of AGVs in the FMS. Authors observed that the fewest number of operations (FNOP), earliest modified due-date (EMDD) and koulamas algorithm yield best results among the all other applied system parameters. The multi-objective task scheduling of AGVs by application of genetic algorithm (GA) and ant colony optimization algorithm (ACO) in the FMS was attempted by [22]. Authors observed that the performance of ACO algorithm was better in comparison to the applied GA. [13] proposed a bidding concept to perform multi-agent criteria scheduling of AGVs in the FMS. Authors validated their approach by applying it to the real-time manufacturing conditions and problems from the literature. Authors observed that the real-time schedules developed by the application of bidding concept were
found to be comparable with the schedules developed from the application of other optimization algorithms. An integrated heuristic for simultaneous optimization of three factors namely minimum makespan, the maximum workload of jobs and total workload [21]. The applied heuristic algorithm divided the objective function into two parts on the basis of the assignment and sequencing of the sub-problem. It was found that initially the algorithm, searches for the assignment space so as to yield acceptable solutions and after that, the algorithm continues the search for the location of optimum sequencing space.

An integrated hybrid genetic algorithm to optimize different AGVs parameters namely such as travel time, makespan, penalty cost due to tardiness and delay due to conflict avoidance is proposed by [23]. Authors considered FMS resources in a holistic way and integrated all resources namely scheduling and dispatch rules, work centers, and AGVs. Authors also applied fuzzy logic so as to control the overall performance of the applied algorithm. It was found that the integrated scheduling of jobs, work centers, and AGVs can always yield optimum results for the FMS. [4-12] performed computational simulation experiments to optimize AGVs fleet size, simultaneous minimization of AGVs distance travel & back-tracking and also scheduling of AGVs in the FMS by the application of the grey wolf optimization algorithm (GWO), clonal selection algorithm (CSA) and MMPSO algorithm. Authors also compared and evaluated the performance of different dispatching rules under different manufacturing scenarios by the application of discrete event simulation in the ARENA application.

It is clearly evident from the literature review that a significant research work has been carried out on the scheduling of AGVs. However, from the literature review, a research gap to address the issue of simultaneous workload balancing and travel time minimization of AGVs in the FMS by application of MMPSO algorithm is established. In order to fill the aforementioned research gap, an attempt is carried out for simultaneous workload balancing and travel time minimization of AGVs in three different FMS layout.

3. **Problem description**

3.1 **Assumptions for the problem**

1. Two AGVs perform material handling activities according to given priorities.
2. The AGV will pick and deliver load for a few numbers of times only.
3. One work can be completed by one AGV at a time.
4. The travel time of AGVs to different work centers was also considered.
5. If both AGVs in the FMS receive a request to serve the same work center in the FMS, then the AGV available at a minimum distance from the work center will be allowed first. And if both AGVs are found to be at equal distance from the work center then the AGV with higher priority will be allowed first to serve work center.
6. There will be no maintenance issue to AGVs.

3.2 **Problem Statement**

Two AGVs are employed to serve in the FMS facility and AGVs scheduling has to be carried out for simultaneous workload balancing and travel time minimization of AGVs by the application of MMPSO algorithm. The formulated combined objective function is described in equation 1.
3.3 Objective Function
The objective function in an analytical form is described as

\[
\text{Minimize } O = q_1 \left( \sum S_1 - \sum S_2 \right) + q_2 \left( \sum S_1 + \sum S_2 \right)
\]

(1)

Where,
\[
\sum S_1 = \text{Total traveling time for AGV}_1
\]
\[
\sum S_2 = \text{Total traveling time for AGV}_2
\]
\[
\sum S_1 - \sum S_2 = \text{Work load balance of AGVs}
\]
\[
\sum S_1 + \sum S_2 = \text{Total travel time of AGVs}
\]

\[q_1 = 0.6, \text{ weight applied for work load balancing.}\]
\[q_2 = 0.4, \text{ weight applied for minimum travel time schedule.}\]

4. Implementation of Algorithm

4.1 Memetic Algorithm
The term ‘meme’ is known as the discrete system of social information which is developed from the interplay of genetic evolution and cultural evolution. The memetic algorithm (MA) represents the generalized genes of the discrete systems. The discrete systems store the information which is exposed to the evolutionary forces for further selection and the variation. In order to find an optimum solution becomes the exploitation of the population with the application of global search technique is carried out. The technique finds the optimum population areas in the predefined search space. The MA applies global search method which is observed to work according to the canonical Genetic Algorithm [3]. In the algorithm, the tournament selection, point mutations, the uniform crossover is carried out. The MA algorithm performs probabilistic bit flipping (point mutations) during the local search which search for same or better solution. The MA represents the genetic evolution and cultural evolution which performs the selection, transmission, inheritance, and variation of memes and genes.

4.2 Modified Memetic Particle Swarm Optimization Algorithm (MMPSO)
The combination of particle swarm optimization (PSO) algorithm and memetic algorithm (MA) develops a modified memetic particle swarm optimization (MMPSO) algorithm. In order to yield good solutions an algorithm performs exploitation (locally searched solutions) and exploration of the solutions (globally searched solutions).

The PSO algorithm communicates with the unit particle in the population of particles for a search of optimum space in the multi-dimensional search space. The particle having some initial speed and a position has a tendency to move at specific points in the multi-dimensional search space. The movement of a particle is dependent on the particle’s velocity which is also referred to as the global best position of a particle in the multi-dimensional search space [15].

For evaluation of the fitness function of the particles, the particles are given some initial random positions \( p(t) \) and velocities \( q_i(t) \). During the iteration of an algorithm according to equation (2), the particle’s position and velocity is changes and updated. The values of fitness function are compared with the previous position and velocity of the particle. If the new solution yield observed to be better than the previously stored solution yield then the new solution value is stored and updated as the best new position of the particle which is also known as \( p_i^{\text{best}} \). The global best solution \( (p_{\text{gbest}}) \) is generated from the whole set of the population.

\[
q_i(t + 1) = q_i(t) + (c_1 \times \text{rand}(\ )) \times (p_i^{\text{best}} - p_i(t)) + (c_2 \times \text{rand}(\ )) \times (p_{\text{gbest}} - p_i(t))
\]

(2)

Where,
\[ q_i(t+1) = \text{Velocity of the } i\text{th particle}, \]
\[ c_1, c_2 = \text{Weight value of local and global best position}, \]
\[ p_i(t) = \text{Position of the } i\text{th particle position at time } t, \]
\[ p_{i\text{best}} = \text{Best-known position for the } i\text{th particle}, \]
\[ p_{gbest} = \text{Particle’s global best position}. \]

The \( \text{rand}() \) function yield uniform random variable \( \in [0, 1] \).

The particle’s new velocity and position is updated according to the equation (2). The equation (2) can be used to find the best position of the particle within the particle local search space at the time interval of \( t \).

The equation (3) is used to update a particle’s new position.

\[ p_i(t+1) = p_i(t) + q_i(t) \quad (3) \]

The first part of the equation (2) represents the velocity component and the second part of the equation interacts with particles current and best position. The interaction of equation is also known as social learning carried out by the algorithm. A Particle’s new position is found and updated according to the equation (3). The application of PSO algorithm converge all the particles at a very early stage towards a specific state. This is also referred to as the exploration stage of the algorithm due to which the particles flow towards the global best position. Therefore there is very less exploitation of particles so as to find the optimum local search solutions. In order to balance the exploration and exploitation parameters of the algorithm, the use of the evolutionary algorithm, for example, the memetic algorithm (MA) found to be highly effective. To yield optimum results from an algorithm, effective local search capabilities of an optimization algorithm are highly required. In this work, MA is applied in combination with the PSO algorithm. The MA is applied for the best local search for the solution and the PSO algorithm is used for the best global search of the solution so as to yield the best simultaneous schedule for the two AGVs serving in the FMS layout. The applied algorithm is referred as modified memetic particle swarm optimization (MMPSO) algorithm. The use of MMPSO algorithm can improve the local search solutions after combining the solutions (particle’s position) similar to the use of crossover function in the GAs.

4.3 Steps of MMPSO algorithm application

Step 1
Particles initialization in the search space and evaluation of the objective function according to PSO algorithm and after that store the local best and global best solution in form of a schedule.

Step 2
Initialize the Memetic algorithm.

Step 3
Recombine the p% of the particle population and after that find and store the new local and global best schedules.

Step 4
Compare the newly found schedule with the previously available schedule. If the newly found schedule is better than the previously found schedule then store the new schedule else use previously stored schedule and delete the new schedule.

Step 5
Update the schedule, and keep the best schedule.

Step 6
Check for end of termination criteria according to the objective function. If the termination criteria are achieved end the algorithm if no repeat all the steps.
5. Numerical example and results

Three sizes of FMS as a standard problem are considered from literature [22] and [10]. The FMS layouts under consideration constitute of 5, 7 and 9 work centers along with one load and unload center in each. Two unit load AGVs are employed for serving work centers in the FMS layouts. While transferring one job from one work center to another the time spent on the transfer of job is taken as AGVs job time. The scheduling of both AGVs has to be carried out to simultaneously minimize the job transfer time and also to balance the workload of both AGVs. The multi-objective scheduling of AGVs is carried out so as to maintain equal job transfer time by AGVs and also the job transfer time shall be minimum. In order to optimize the multi-objective schedule, the MMPSO algorithm is applied. The AGVs and work center travel-time information for layout 1, 2 and 3 are mentioned in table 1, 2 and 3 respectively [22] and [10]. The normalized weights are applied as $q_1 = 0.6$, $q_2 = 0.4$ so as to balance the job transfer load and also to minimize the job transfer travel time of AGVs in the above stated FMS layouts respectively. The MMPSO algorithm is applied and iterated on Intel(R) Core(TM) i5 system specifications. The MMPSO algorithm was iterated for 60 times and then cooled off. The results obtained from MMPSO algorithm is presented in table 4 and also compared with the results gained from other algorithms namely GA, ACO and GWO, from the literature [22] and [10]. From the results, it is evident that the application of MMPSO algorithm significantly outperforms the results yield of GA, ACO and GWO for all three FMS layouts.

| Table 1. AGV-Work center travel-time information for FMS layout 1 |
| AGV | Work centers |
| W1 | W2 | W3 |
| 1 | 20 | 25 | 40 |
| 2 | 25 | 30 | 45 |

| Table 2. AGV-Work center travel-time information for FMS layout 2 |
| AGV | Work centers |
| W1 | W2 | W3 | W4 |
| 1 | 18 | 21 | 43 | 48 |
| 2 | 15 | 16 | 42 | 50 |

| Table 3. AGV-Work center travel-time information for FMS layout 3 |
| AGV | Work centers |
| W1 | W2 | W3 | W4 | W5 |
| 1 | 20 | 25 | 35 | 42 | 54 |
| 2 | 25 | 40 | 45 | 50 | 55 |
6. Conclusion

In this paper, the multi-objective scheduling for two unit load AGVs serving in three different sizes of FMS layouts is performed. The formulated combined objective function was to balance the AGVs workload and their travel time simultaneously. In order to yield optimum schedules for AGVs, the MMPSO algorithm was applied. The output results of MMPSO algorithm is evaluated and compared with the output results of GA, ACO and GWO from the literature. It becomes clearly evident that the application of the MMPSO algorithm declines the combined objective function and also increases the overall utilization of the FMS resources in comparison to the other applied heuristic algorithms from the literature. The proposed methods can also be attempted for different FMS production scenarios after considering other FMS parameters.

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### Table 4. Comparison of the resulting yield for the three sizes of FMS layout by different algorithms

| S.No. | FMS layout | GA [22] | ACO [22] | GWO [10] | MMPSO (Proposed) |
|-------|-----------|---------|----------|---------|------------------|
| 1     | 1         | 185     | 184      | 180     | 179              |
| 2     | 2         | 210     | 204      | 198     | 193              |
| 3     | 3         | 242     | 238      | 229     | 221              |
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