Process Planning and Scheduling with SLK Due-Date Assignment where Earliness, Tardiness and Due-Dates are Punished

Halil Ibrahim Demir, Ozer Uygun, Ibrahim Cil, Mumtaz Ipek, and Meral Sari
Industrial Engineering Department, Sakarya University, Sakarya, Turkey
Email: {hidemir, ouygun, icil, ipek, meralsari}@sakarya.edu.tr

Abstract—Traditionally process planning, scheduling and due date assignment are treated separately. Some works are done on integrated process planning and scheduling and on scheduling with due-date assignment. However integrating all of these functions is not treated. Since scheduling problems alone belong to NP-hard class problems, integrated problems are even harder to solve. In this study process planning and scheduling and SLK due date assignment are integrated using genetic algorithms and Random search techniques. Earliness, Tardiness and length of due-dates are punished. While earliness and tardiness are punished quadratically, due-date is punished linearly. Three results were compared. One is ordinary solution, another one is random search solution and the third one is genetic algorithm solution. Genetic algorithm solution outperforms the other solutions and Random search solution is the second best and ordinary solution is the worst solution.

Index Terms—process planning, scheduling, due-date assignment, genetic algorithm, random search

I. INTRODUCTION

Process planning, scheduling and due-date assignment are three important functions and traditionally they are treated separately. In this competitive era firms should work more efficient and keep promises they gave, be successful in process planning, scheduling and due-date assignment. Since these three functions are done separately, they do not care each other and independently applied functions cause great loss in global performance. If we look at each function one by one; Process planning has been defined by Society of Manufacturing Engineers as the systematic determination of the methods by which a product is to be manufactured economically and competitively. As we will see alternative process plans help to improve quality of scheduling and due-date assignment. Outputs of process plans are inputs to scheduling. If process planners do not care about scheduling and due date assignment they can prepare poor inputs and they can select some machines repeatedly and cause bottleneck machines in shop floor. This can cause unbalanced workload in shop floor. If there are no alternative process plans then we have no flexibility when required. In case of congestion and customer demand it will be helpful to have alternative process plans to use idle resource or to response customer demand better.

According to Zhang and Mallur [1] production scheduling is a resource allocator, which considers timing information while allocating resources to the tasks. Developments in computer makes easy and quality process plans possible, that’s why it becomes easy to prepare alternative process plans. Scheduling with flexible process plans may allow us to take corrective action in case of need, So that we can redirect jobs from congested machines to starving machines. This causes better balanced workshop load and increases throughput rate and with alternative process plans we can handle machine breakdowns and unexpected occurrences.

Due dates are determined internally or externally. If due dates are determined externally we should meet due dates otherwise we pay for tardiness. In JIT environment earliness is also undesired so we try to minimize earliness and tardiness. That’s why integration of process planning and scheduling with due-dates helps us to minimize earliness and tardiness cost. If due-dates are determined internally we should determine best due-date that minimizes some costs, such as; Tardiness, Earliness and length of due-date. Tardiness are undesired and it means loss of customer good-will or even we can lose customer, Earliness is also unwanted because of inventory holding cost, space and spoilage etc. Length of due dates are also important to consider. Long due dates can cause to lose customer or can be a reason in price reduction. That’s why we should minimize earliness, tardiness and due-date related costs and give a due-date to a customer that minimizes some function of these costs.

II. RELATED RESEARCHES

There are numerous work done on integrated process planning and scheduling and about scheduling with due-date assignment. But integration of these three functions are not mentioned much in the literature. Demir et al [2] mentioned about integrated process planning scheduling and due-date assignment. In this study integration of process planning and scheduling with SLK due-date assignment was studied. Earliness, Tardiness and due-
dates are punished. Earliness and Tardiness are symmetrically and quadratically and due-dates are linearly punished.

We mentioned that there are numerous work on integrated process planning and scheduling. If we mention some of these researches; Nasr and Elsayed [3] developed two algorithms to minimize the mean flow time in job shop scheduling with alternative machine tool routings. In general, the proposed algorithms present efficient solutions to the scheduling problem in such a system. These algorithms are able to solve large scale problems in a very short time. Khosnevis and Chen [4] addressed the basic issues involved in the integration of the two functions, demonstrated a methodology and the potential benefits of the integration approach by an example. Hutchinson et al [5] examined the influences that scheduling schemes and the degree of routing flexibility have on random, job shop flexible manufacturing systems within a static environment. Jiang and Chen [6] investigated the relationships between the alternate process planning and the scheduling performance regarding to three different criteria; they are mean tardiness, mean work-in-process, and mean machine utilization. Chen and Khosnevis [7] investigated the problem of integrating the process planning and scheduling functions as a scheduling problem with flexible process plans. Zhang and Mallur [1] proposed an integrated model for process planning and job shop scheduling. Their approach can lead to more structured decision making on the shop floor and hence the creation of feasible plans.

While exploiting process plan flexibility in production scheduling, Brandimarte [8] used multi-objective approach. The problem of solving scheduling problems involving multiple process plans per job was addressed by Kim and Egbelu [9]. In their research Morad and Zalzala [10] used genetic algorithm and they considered also some other objectives other than time aspects. These objectives are minimizing makespan, minimizing total rejects produced and minimization of total cost of production. Ming and Mak [11] tried to provide a good solution to the process plan selection by using a hybrid Hopfield network-genetic algorithm. Tan and Khosnevis [12] presented a review on integrated process planning and scheduling. Lee and Kim [13] proposed simulation based genetic algorithm as a new approach to the integration of process planning and scheduling.

To handle the two functions, process planning and scheduling, at the same time Kim et al [14] presented a new method using artificial intelligent search technique, called symbiotic evolutionary algorithm. Kumar and Rajotia [15] studied the integration of CAPP (Computer Aided Process Planning) and scheduling. Usher [16] addressed the benefit of alternative process plans and worked on the number of alternative process plans. For the purpose of increasing the responsiveness of adaptive manufacturing systems in accommodating dynamic market changes, Lim and Zhang [17] aimed to develop a system to integrate dynamic process planning and dynamic production scheduling. For the integration of process planning and scheduling problem, a linearized polynomial mixed-integer programming model (PMIPM) was presented by Tan and Khosnevis [18]. Kumar and Rajotia [19] proposed a framework for integration of process planning with production scheduling. Ueda et al [20] proposed a new simultaneous process planning and scheduling method. Moon et al [21] studied integrated process planning and scheduling (IPPS) in a supply chain.


If we look at the literature we see that it is hard to solve integrated problems. Some solutions are only possible for small problems. For IPPS at the literature people use genetic algorithms, evolutionary algorithms or agent based approach for integration, or they decompose problems because of complexity of the problem. They decompose problems into loading and scheduling subproblems. They use mixed integer programming at the loading part and heuristics at the scheduling part.

Due-date performance is becoming increasingly important in today’s competitive environment. Gordon et al [26] presented a state of the art review on scheduling with due date assignment. There are two aspects of due-date performance; delivery reliability and delivery speed [27]. Delivery reliability is the ability to constantly meet promised delivery dates. Delivery speed is the ability to deliver orders to the customer with short leadtimes. Customers are less willing to accept long promised leadtimes Philipoom [28]. At literature there are numerous work done on scheduling with due-date assignment. In this study SLK due-date assignment is integrated with scheduling and process planning using genetic algorithm. Experiment results shows the benefits of integration of SLK due-date assignment.

In his study Baker [29] studied the interaction between sequencing priorities and the method of assigning due-dates. Cheng [30] who contributed a lot to this area studied optimal due-date assignment in a job shop. Cheng [31] presented a study of a hypothetical job shop by computer simulation. He aimed to investigate the main and interaction effects of three shop decision variables: the job dispatching rule, the due-date assignment method and, shop load ratio on a shop performance measure. Luss and Rosenwein [32] developed a heuristic, due date assignment algorithm, for multiproduct manufacturing facilities to solve the order acceptance problem. Their objective was to minimize the sum of weighted (positive) deviations of the assigned due dates from the requested dates. Lawrence [33] presented a methodology for negotiating due-dates between customers and producers in complex manufacturing
environments. In their paper Yang et al [34] studied the generalized job shop scheduling problem with due dates wherein the objective is to minimize total job tardiness. For solving this problem they presented an efficient heuristic algorithm called revised exchange heuristic algorithm (REHA). Kahlbacher and Cheng [35] studied the problem of scheduling n jobs on a single machine. Each job is assigned a processing-plus-wait due date and objective was to minimize the symmetric earliness and tardiness costs.

There are many works on single machine scheduling and due date assignment. Qi et al [36] studied a new subclass of machine scheduling problems in which due dates are treated as variables and must be assigned to the individual jobs. A solution then is a sequence of jobs along with due date assignments. Lauff and Werner [37] studied multi-machine problems and penalized earliness and tardiness and scheduled jobs with common due date. Cheng et al. [38] studied the problem of scheduling jobs whose processing times are decreasing functions of their starting times. They considered the case of a single machine and a common decreasing rate for the processing times. The problem was to determine an optimal combination of the due date and schedule so as to minimize the sum of due date, earliness and tardiness penalties. Wang [39] considered a single machine scheduling problem with a common due date. Job processing times were controllable to the extent that they can be reduced, up to a certain limit, at a cost proportional to the reduction.

Xia et al [40] considered due date assignment and sequencing for multiple jobs in a single machine shop. The processing time of each job was assumed to be uncertain and was characterized by a mean and a variance with no knowledge of the entire distribution. Shabty and Steiner [41] studied two due-date assignment problems in various multi-machine scheduling environments. They assumed that each job can be assigned an arbitrary non-negative due date, but longer due dates have higher cost. At the first function they included earliness, tardiness and due date assignment costs. In the second problem they minimized an objective function that includes number of tardy jobs and due date assignment costs. Baykasoglu et al [42] studied new approaches to due date assignment in job shops. Their primary objective was to compare the performance of the proposed due date assignment model (PDDAM) with several conventional due date assignment models (CDDAM).

Gordon and Strusevich [43] considered single machine scheduling and due date assignment problems in which the processing time of a job depends on its position in a processing sequence. The objective functions include the cost of changing due the due dates, the total cost of discarded jobs that cannot be completed by their due dates and, possibly, the total earliness of the scheduled jobs. Tuong and Soukhal [44] studied due date assignment and just-in-time scheduling for single machine and parallel machine problems with equal-size jobs where the objective is to minimize the total weighted earliness-tardiness and due date cost. Vinod and Sridharan [45] presented salient aspects of a simulation study conducted to investigate the interaction between due-date assignment methods and scheduling rules in a typical dynamic job shop production system. The due-date assignment methods investigated are dynamic processing plus waiting time, total work content, dynamic total work content and random work content method.

In their article Yin et al [46] addressed a single machine scheduling problem with simultaneous consideration of due-date assignment, generalised position-dependent deteriorating jobs, and deteriorating maintenance activities. Lu et al [47] considered a single-machine earliness-tardiness scheduling problem with due-date assignment, in which the processing time of a job is a function of its position in a sequence and its resource allocation. Hazir and Sidhoum [48] addressed the optimal batch sizing and just-in-time scheduling problem. Their objective was to find a feasible schedule that minimizes the sum of the weighted earliness and tardiness penalties as well as the setup costs. Yin et al [49] studied batch delivery scheduling on a single machine, where a common due-date is assigned to all the jobs and a rate-modifying activity on the machine may be scheduled, which can change the processing rate of the machine.

### III. Problem Definition

In this study we studied integration of IPPS (Integrated process planning and scheduling) with Due-date assignment (with SLK due date assignment). There are alternative routes of each job in a job shop environment and we have alternative dispatching rules (eight dispatching rules with different multipliers we have ten dispatching rules) and we have SLK due date assignment method (SLK due date assignment represents internal due date assignment). For the comparison we also tested RDM (Random) due date assignment that represent external due date assignment.

<table>
<thead>
<tr>
<th>Shop floor</th>
<th>Shop floor 1</th>
<th>Shop floor 2</th>
<th>Shop floor 3</th>
</tr>
</thead>
<tbody>
<tr>
<td># of machines</td>
<td>20</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td># of Jobs</td>
<td>50</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td># of Routes</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Processing Times</td>
<td>(10 +</td>
<td>z</td>
<td>* 3)</td>
</tr>
<tr>
<td># of op. per job</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

We have three sized shop floor. First is small shop floor with 50 jobs and 20 machines, second is medium sized shop floor with 100 jobs 30 machines and third is big sized shop floor with 200 jobs and 40 machines. At small and medium sized shop floors, jobs have five alternative routes and at the big sized shop floor, jobs have three alternative routes. In every case we have 10 operations for each job. Processing times practically change in between 10 and 19 according to the given formula (Processing times = (10 + |z| * 3) = nearest small integer in between 10 and 19. |z| is absolute value
of standard normal numbers). Processing times are randomly produced. Characteristics of the shop floors are given at Table I.

In this study we penalized earliness and tardiness symmetrically. We accepted one day as one shift and 8 hours. 8 hours make $8 \times 60 = 480$ minutes so one day is 480 minutes. If jobs are early and late within one day we used linear punishment (Since quadratic punishment is very small). If jobs are early and late for more than one day then we used quadratic punishment. In case of due date we penalized length of due date linearly. Punishment functions are given below where $PD$ is penalty for due-date, $PE$ is penalty for earliness and $PT$ is penalty for tardiness;

$$P.D = 8^*(Due-date/480) \quad (1)$$

$$PE = \begin{cases} 
8^*(E/480) & \text{if } E \leq 480 \\
8^*(E/480)* (E/480) & \text{if } E > 480 
\end{cases} \quad (2)$$

$$PT = \begin{cases} 
8^*(T/480) & \text{if } T \leq 480 \\
8^*(T/480)* (T/480) & \text{if } T > 480 
\end{cases} \quad (3)$$

IV. USED TECHNIQUES

In this study three solution techniques are compared. We compared genetic search (genetic algorithm) technique with random search technique and with ordinary solution.

Genetic Search: At genetic search we used crossover and mutation operator and produce two population, crossover population and mutation population and with the final-old population we compare three populations and select $n$ best chromosome (solution) as the new population. This makes one iteration. We repeat iterations until a predetermined value and it changes according to the size of the shop.

Random Search: At random search, at each iteration we produced new random solutions as big as crossover population and mutation population. Among these three populations (final main population and two new produced populations) we selected best $n$ solutions for the new main population and we finish one iteration and pass to the next iteration. At random search we produce two new populations equal sized with crossover and mutation population so that comparison of random search and genetic search becomes fairer.

<table>
<thead>
<tr>
<th>DD</th>
<th>DR</th>
<th>$R_{j1}$</th>
<th>$R_{j2}$</th>
<th>...</th>
<th>$R_{jn}$</th>
</tr>
</thead>
</table>

Where

DD: Due date assignment gene
DR: Dispatching rule gene
$R_{nj}$: $j$’th route of job $n$

![Figure 1. Sample chromosome.](image)

Ordinary solution: At ordinary solution we randomly produced three population. One is main population and two populations equally sized with crossover population and mutation population. Later we chose $n$ best solutions for the initial main population. This is like one iteration in genetic search and random search. We used these solutions as ordinary solutions. Later we compared these solutions and made comment on these solutions.

We represented solutions (individuals) as chromosome which consists of number of jobs plus two genes for SLK due-date assignment and dispatching rules as illustrated in Fig. 1.

Due dates were assigned using mainly two different types of rules. Considering different constants the first gene took one of four values. These rules are explained below at Table II and at Appendix A:

<table>
<thead>
<tr>
<th>Method</th>
<th>Multiplier $k$</th>
<th>Constant $q_k$</th>
<th>Rule no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLK</td>
<td>$q_k = q_1, q_2, q_3$</td>
<td>1,2,3</td>
<td></td>
</tr>
<tr>
<td>RDM</td>
<td></td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

In order to dispatch eighth different methods were used. Considering different multipliers, the second gene took one of ten different values. Dispatching rules are given and explained at Table III and at Appendix B.

TABLE II. DUE-DATE ASSIGNMENT RULES

<table>
<thead>
<tr>
<th>Method</th>
<th>Multiplier $k$</th>
<th>Constant $q_k$</th>
<th>Rule no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATC</td>
<td>$k = 1,2,3$</td>
<td></td>
<td>1,2,3</td>
</tr>
<tr>
<td>MS</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>SPT</td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>LPT</td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>SOT</td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>EDD</td>
<td></td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>ERD</td>
<td></td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>SIRO</td>
<td></td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

TABLE III. DISPATCHING RULES

<table>
<thead>
<tr>
<th>Method</th>
<th>Multiplier $k$</th>
<th>Rule no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIRO</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

V. COMPARED SOLUTIONS

SCH-SLK (Ordinary): Process planning, Scheduling and SLK due date assignment are integrated and ordinary solution is taken. Ordinary means just one iteration applied and initial population is taken without making any directed or undirected search. SLK means due-dates are not externally (randomly and predetermined) determined rather it is internally and integrally determined with dispatching rules and route selection.

SCH-RDM (Ordinary): Process planning and scheduling integrated, due dates are randomly determined that represent external due-dates. Ordinary solution is taken. No directed or undirected search is applied.

SIRO-RDM (Ordinary): In this solution scheduling and due-date determinations are unintegrated. One of alternative routes is selected and SIRO (Service in random order) dispatching rule is used to represent unintegrated scheduling and RDM (Random) due-date determination is used to represent unintegrated due-date assignment.

SCH-SLK (Random): Above solutions were first iteration solutions (No directed or undirected search are applied) but this solutions apply undirected search. For small shop floor we apply 200 random iterations, for
medium sized shop floor we apply 100 random iterations and for large shop floor we apply 50 random iterations. Here scheduling and SLK due-date assignment are integrated with process planning.

**SCH-SLK (Genetic):** Here scheduling and SLK due-date assignment are integrated with process planning. Genetic (Directed) search is applied to the problem. For small shop we apply 200 genetic iterations, for mid-size shopfloor we apply 100 genetic iterations and for large shop floor we apply 50 genetic iterations. Since genetic (directed) search is better than random (undirected) search we used genetic iterations for the solutions below.

**SCH-RDM (Genetic):** Here scheduling is integrated with process planning but due-dates are determined randomly and genetic search is applied.

**SIRO-RDM (Genetic):** In this solution scheduling and due-date determination are unintegrated with process planning. SIRO dispatching rule is used and RDM due-date assignment is used and genetic search is applied.

We compared above seven solutions with each other to determine whether integration of scheduling with process planning is beneficial and whether integration of due-date assignment with process planning and scheduling is beneficial. We also tested directed and undirected search for three shop floors and genetic search is found better. Results are given at experimentation part and interpreted at conclusion part.

VI. EXPERIMENTATION

We coded shop floor at C++ language and run the program on a Laptop with 2 GHz processor. We produced data for three shop floors and coded integrated process planning, scheduling and due-date assignment problem and coded random and genetic search. For different shop floors we applied given number of random and genetic iterations. For small shop floor we used 200 iterations and it took approximately 100 seconds to finish 200 iterations. For medium sized shop floor we applied 100 iterations and it took approximately 500 seconds to finish 100 iterations. For large shop floor we applied 50 iterations and it took 600 seconds to finish 50 iterations.

We tested three shop floors for seven types of solutions. We first looked at unintegrated process planning scheduling and due-date assignment as SIRO-RDM (Genetic) and SIRO-RDM (Ordinary). Later we integrated scheduling with process planning and used Random due-date assignment. At these solutions we looked at SCH-RDM (Genetic) and SCH-RDM (Ordinary) solutions. Finally we integrated process planning, scheduling and SLK Due-date assignment and looked at solutions SCH-SLK (Genetic), SCH-SLK (Random), SCH-SLK (ordinary). Explanations of these solutions are given at section 5.

We tested three shop floors for seven types of solutions. First shop floor is small shop floor and there are 20 machines, 50 jobs with 10 operations each and each job has 5 alternative process plans and processing times of each operation changes in between 10 and 19 according to following formula ⌊(10 + |z| * 3)⌋. We compared seven solutions and three of them are ordinary solutions and use first step (initial step, can be considered as first iteration) solutions. One of them use random search and we make 200 random iterations. Three of the solutions use genetic search and we apply 200 genetic search iterations. Results are given below for the small shop floor. Getting ordinary solution occurs at the very beginning of the iterations so negligible time required for ordinary solutions. Applying 200 random or genetic iterations require approximately 100 seconds (cpu time). Times are given at Table IV at the last column. Results of small shop floor are given at Table IV and at Fig. 2. According to results the more the solutions are integrated the results are better and the more search iteration applied the solution is better and directed search outperform undirected search.

**TABLE IV: COMPARISON OF SEVEN TYPES OF SOLUTIONS FOR SMALL SHOP FLOOR**

<table>
<thead>
<tr>
<th></th>
<th>Worst</th>
<th>Average</th>
<th>Best</th>
<th>Cpu time</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCH-SLK (O)</td>
<td>424.24</td>
<td>308.82</td>
<td>238.54</td>
<td></td>
</tr>
<tr>
<td>SCH-RDM(O)</td>
<td>448.56</td>
<td>419.08</td>
<td>390.68</td>
<td></td>
</tr>
<tr>
<td>SIRO-RDM(O)</td>
<td>430.92</td>
<td>423.04</td>
<td>413.05</td>
<td></td>
</tr>
<tr>
<td>SCH-SLK (R)</td>
<td>237.34</td>
<td>236.05</td>
<td>233.82</td>
<td>115sec</td>
</tr>
<tr>
<td>SCH-SLK (G)</td>
<td>227.9</td>
<td>226.38</td>
<td>225.33</td>
<td>92sec</td>
</tr>
<tr>
<td>SCH-RDM(G)</td>
<td>376.16</td>
<td>375.69</td>
<td>374.93</td>
<td>111sec</td>
</tr>
<tr>
<td>SIRO-RDM(G)</td>
<td>399.12</td>
<td>397.64</td>
<td>394.82</td>
<td>89sec</td>
</tr>
</tbody>
</table>

**TABLE V: COMPARISON OF SEVEN TYPES OF SOLUTIONS FOR MEDIUM SHOP FLOOR**

<table>
<thead>
<tr>
<th></th>
<th>Worst</th>
<th>Average</th>
<th>Best</th>
<th>Cpu time</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCH-SLK (O)</td>
<td>840.27</td>
<td>676.03</td>
<td>598.33</td>
<td></td>
</tr>
<tr>
<td>SCH-RDM(O)</td>
<td>893.2</td>
<td>827.32</td>
<td>755.19</td>
<td></td>
</tr>
<tr>
<td>SIRO-RDM(O)</td>
<td>830.59</td>
<td>806.89</td>
<td>784.22</td>
<td></td>
</tr>
<tr>
<td>SCH-SLK (R)</td>
<td>574.6</td>
<td>569.63</td>
<td>562.73</td>
<td>326sec</td>
</tr>
<tr>
<td>SCH-SLK (G)</td>
<td>541.55</td>
<td>540.3</td>
<td>539.03</td>
<td>261sec</td>
</tr>
<tr>
<td>SCH-RDM(G)</td>
<td>732.89</td>
<td>732.35</td>
<td>731.85</td>
<td>303sec</td>
</tr>
<tr>
<td>SIRO-RDM(G)</td>
<td>774.45</td>
<td>772.71</td>
<td>768.9</td>
<td>250sec</td>
</tr>
</tbody>
</table>

![Figure 2. Small shop floor results](image-url)
Similar results are found for the second mid-size shop floor and these results are given at the following Table V and Fig. 3.

Third shop floor is the biggest shop floor and similar results are found in this shop floor. Results are summarized at the following Table VI and Fig. 4.

**Figure 4. Large shop floor results**

**TABLE VI: COMPARISON OF SEVEN TYPES OF SOLUTIONS FOR LARGE SHOP FLOOR**

<table>
<thead>
<tr>
<th></th>
<th>WORST</th>
<th>AVG.</th>
<th>BEST</th>
<th>CPU TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCH-SLK (O)</td>
<td>2069.26</td>
<td>1837.38</td>
<td>1664.24</td>
<td></td>
</tr>
<tr>
<td>SCH-RDM(O)</td>
<td>2061.26</td>
<td>1896.34</td>
<td>1770.73</td>
<td></td>
</tr>
<tr>
<td>SIRO-RDM(O)</td>
<td>1936.56</td>
<td>1910.79</td>
<td>1886.14</td>
<td></td>
</tr>
<tr>
<td>SCH-SLK (R)</td>
<td>1559.32</td>
<td>1547.93</td>
<td>1531.39</td>
<td>628sn</td>
</tr>
<tr>
<td>SCH-SLK (G)</td>
<td>1475.92</td>
<td>1473.64</td>
<td>1467.52</td>
<td>507sn</td>
</tr>
<tr>
<td>SCH-RDM(G)</td>
<td>1706.57</td>
<td>1704.1</td>
<td>1701.61</td>
<td>814sn</td>
</tr>
<tr>
<td>SIRO-RDM(G)</td>
<td>1813.14</td>
<td>1808.31</td>
<td>1797.27</td>
<td>515sn</td>
</tr>
</tbody>
</table>

**Figure 3. Medium shop floor results**

**VII. CONCLUSION**

In this study we tried to integrate process planning, scheduling and SLK due-date assignment. We compared different integration level. At first we took scheduling and due-date assignment as unintegrated we solved problem for SIRO-RDM (Genetic) and SIRO-RDM (Ordinary). Here we assumed that scheduling is unintegrated and we used SIRO (Service in random order) dispatching. We also assumed due-date determination is unintegrated and we used RDM (Random) due-date assignment in place of external, unintegrated due-date determination.

Later we integrated scheduling with process plan selection. At solution (chromosome), at dispatching rule gene we used with multipliers ten different dispatching rules. These dispatching rules are given at section 4. Here still we determined due-date randomly (externally) and we didn’t integrate due date determination with process plan selection and scheduling. We solved problem for SCH-RDM (Genetic) and for SCH-RDM (Ordinary).

Later we integrated three functions (process planning, scheduling and due-date assignment). At solution (chromosome), at scheduling gene we used ten dispatching rules and at due-date assignment gene we used 4 types of due-date assignment, with three different slack constant we used three different SLK due date assignment and we used one RDM (Random) due-date assignment method. Here we solved problem for SCH-SLK (Genetic), SCH-SLK (Random), and SCH-SLK (Ordinary) cases. At genetic search we repeated genetic iterations up to 200, 100 and 50 iterations for small, medium and large sized shop floors. At Random search we applied these many random iterations for three different shop floors. Totally these seven types of solutions and their explanations are given at section 5.

If these three functions are performed sequentially and separately then they can become very poor input to the next stage. Increasing competitiveness force firms to determine more reliable due-dates and keep their promises and force them to be flexible and to be successful at shop floor utilization and scheduling. If process plans are not integrated with scheduling and due-date determination then poor inputs can be produced for the downstream. Repeatedly most desired machines can be selected and these cause unbalanced machine load and some machines become bottleneck while others starving. Also unintegrated case do not consider machine breakdown, unbalanced workload and other unexpected and unwanted occurrences. If we integrate these three functions then we can reduce the effect of these troubles, we can get better loaded shop floor, we can assign better due date, keep our promise, and satisfy customers.

When we look at the seven types of solution; first observation is the more integration we succeeded the better the solution we got. Second observation is directed and undirected searches give better performance than ordinary solutions. Final observation we get, genetic (directed) search outperforms random (undirected) search.
APPENDIX A: DUE-DATE ASSIGNMENT RULES

- SLK (Slack) $\rightarrow$ Due = TPT $+ q_s$
- RDM (Random due assign.) $\rightarrow$ Due = $N - (3P_{av} + P_{av}/2)^2$
- TPT= total processing time
- $P_{av}$= mean processing time of all job waiting

APPENDIX B: DISPATCHING RULES

ATC (Apparent Tardiness Cost): This is composite dispatching rule, and it is a hybrid of MS and SPT.

MS: Minimum Slack First
SPT: Shortest Processing Time First
LPT: Longest Processing Time First
SOT: Shortest Operation Time First
EDD: Earliest Due-Date First
ERD: Earliest Release Date First
SIRO (Service in Random order): A job among waiting jobs is selected randomly to be processed.

REFERENCES


Halil Ibrahim Demir was born in Sivas, Turkey in 1971. In 1988 he got full scholarship and entered Bilkent University, Ankara, Turkey to Industrial Engineering Department. He got his Bachelor of Science degree in Industrial Engineering in 1993.

In 1993 he went to Germany for graduate study. He studied German up to intermediate level. In 1994 he got full scholarship for graduate study in USA from ministry of Education of Turkey. In 1997 he got Master of Science degree in Industrial Engineering from Lehigh University, Bethlehem, Pennsylvania, USA. He is accepted to Northeastern University, Boston, Massachusetts for Ph.D. study. He finished Ph.D. courses at this university and completed Ph.D. thesis at Sakarya University, Turkey in 2005 and got Ph.D. degree in Industrial Engineering.

He started to his academic position at Sakarya University and works as an Assistant Professor at this university.

Ozer Uygün is an Assistant professor at Sakarya University

İbrahim Cil is a Professor at Sakarya University

Mumtaz İpek is an Assistant professor at Sakarya University

Meral Sari is Master of Science student at Sakarya University


2015 Engineering and Technology Publishing