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SOLVING PROCESS PLANNING, WEIGHTED APPARENT TARDINESS COST DISPATCHING, AND WEIGHTED PROCESSING PLUS WEIGHT DUE-DATE ASSIGNMENT SIMULTANEOUSLY USING A HYBRID SEARCH

ABSTRACT

Process planning, scheduling, and due date assignment play crucial role in manufacturing systems in terms of efficient and flexible production. Integration of the production functions has been studied in the literature. In this context, there are hundreds of works on integrated process planning and scheduling (IPPS) and scheduling with due date assignment (SWDDA) problems. In this paper, we extend the existing literature works on integrated process planning, scheduling and due date assignment (IPPSDDA) using a hybrid search algorithm. Since the scheduling problem is in the NP-Hard problem class without any integration, integrated problem is even harder to solve. This study focuses on the integration of these functions. Sum of weighted tardiness, earliness, and due date related costs are used as a penalty function. Random search and hybrid meta-heuristics are used to solve integrated problem. We used hybrid and random search techniques while solving the integrated problem. Full integration with hybrid search is found as the best combination. So, hybrid search outperformed random search and ordinary solutions were very poor compared to the search results.

Keywords: Process Planning and Scheduling, Scheduling with due date Assignment, Genetic Algorithms, Hybrid Search, Weighted Due-Date Assignment

1. INTRODUCTION

According to Society of Manufacturing Engineers process planning is the systematic determination of the methods by which a product is to be manufactured economically and competitively. Zhang and Mallur stated that production scheduling is as a resource allocator, which considers timing information while allocating resources to the tasks [1]. "The problems with due-date determination have received considerable attention in the last 15 years due to the introduction of new methods of inventory management such as just-in-time (JIT) concepts. In JIT systems jobs are to be completed neither too early nor too late which leads to the scheduling problems with both earliness and tardiness costs and assigning due dates [2]". Although classically these three important manufacturing functions performed

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independently, high interrelations among them made researchers to study integrated problems. Although there are hundreds of works on SWDDA (scheduling with due date assignment) and on IPPS problems, there are only a few works on IPPSDAA (Integrated process planning, scheduling and due date assignment). At this research we integrated process plan selection with WATC (Weighted Apparent tardiness cost) weighted dispatching and WPPW (Weighted process plus weight) weighted due date assignment. Since there is high interrelation among these functions we should better consider them concurrently. Outputs of upstream functions may become inputs to downstream functions. Process planning outputs become inputs to scheduling at the shop floor level. Quality process plans may improve shop floor performance and cause better balanced workloads or vice versa. If process planning is made independently then process planners may select some machines repeatedly and may select some other machines seldom. This substantially reduce shop floor performance and cause unbalanced shop floor loading. Some machines become bottleneck and some machines may be starving. Similarly, it is better to consider due date assignment and scheduling concurrently. If due dates are determined independently we may give unrealistically far or close due dates.

At the former case we pay for earliness and due date related costs, loss of good will, price reduction and worse customer loss and at the latter case we may not keep our promise and pay for high tardiness, price reduction, loss of good will and customer loss. This time if scheduling is performed independently then we may schedule jobs with far due dates earlier or vice versa. Many works at literature are on scheduling with common due date assignment. If there are jobs waiting to be assembled, then we need to assign common due dates. Here at this study we schedule n jobs before m machines and every job have unique routes and we assign separate due dates for each job. Traditionally tardiness is punished but at JIT approach we should penalize both earliness and tardiness. At this study we added due date related costs and we panelized weighted due dates also. Far due dates for important customer are punished most or vice versa. Since neither customer desires long due dates it was reasonable to penalize due dates. As a summary we panelized sum of weighted tardiness, earliness and due date related costs. Since we applied WPPW weighted due date assignment rule, we assigned closer due dates for more important customers and by using WATC scheduling rule we scheduled important customers with minimum slack and shorter processing times earlier. As a result, we expected to save substantially from the sum of weighted earliness, tardiness and due date related costs. Because only scheduling sub problem is NP-Hard problem we used hybrid and random search metaheuristics while solving the integrated problem. If we explain why we used hybrid search; Random search is very efficient at the beginning and marginal improvement is very high at earlier iterations and expected marginal benefit reduce sharply as iterations go on. So, it is reasonable to use random search at the beginning. Genetic search is directed search and uses best results so far to produce new solutions.

That is why genetic search is more powerful compared to random search especially as iterations goes on. So, we combined power of random search and genetic search and we produced hybrid search. We used chromosomes while representing integrated problem. A chromosome consists of (n+2) genes where initial two genes are about due date assignment rule and dispatching rule. Remaining genes about the selected routes of every job. Since first two genes have very high impact over performance function compared to remaining n genes, we gave very high probabilities for these two genes compared to the remaining genes while selecting dominant genes for crossover and mutation operators. Initially we tested unintegrated combinations for comparison purpose and to observe how poor these combinations are. Later we integrated these functions one by one and at the end we tested fully integrated combinations to prove higher integration level is better. Full integration was the goal of this study and we wanted to see this level as the best integration level.

2. RESEARCH SIGNIFICANCE

In this paper, integrated process planning, scheduling and due date assignment (IPPSDDA) was studied using a hybrid search algorithm. Since the scheduling problem is in the NP-Hard problem class without any integration, integrated problem is even harder to solve. This study focuses on the integration of these functions. Sum of weighted tardiness, earliness, and due date related costs are used as a penalty function. Random search and hybrid meta-heuristics are used to solve integrated problem. We used hybrid and random search techniques while solving the integrated problem. Full integration with hybrid search is found as the best combination. So, hybrid search outperformed random search and ordinary solutions were very poor compared to the search results.

3. LITERATURE REVIEW ON INTEGRATED PROBLEMS

Although there are only a few works on IPPSDDA problem, there are substantial amount of works done on IPPS and SWDDA problem. By these works process planning, scheduling and due date assignment functions are tried to be integrated. Although integrated problems increase problem complexity, they improve overall performance. This is because there are high interrelations between these three important functions. At the first problem three functions are tried to be integrated and there are only a few works done on this area. At the second integrated problem process planning and scheduling are tried to be integrated and finally at the third problem scheduling and due date assignment are tried to be integrated. As a beginning if we give some literature on IPPSDDA problem, we can give following examples; [3 and 6] are some examples to the full integration of the three functions. IPPS is one of integration and there are numerous works are done on this problem. Here process planning is integrated with scheduling. Since only scheduling problem is NP-Hard problem, integrated problem becomes even more complex. That is why exact solutions are only possible for only very small sized problems and researchers uses some heuristics to find a good solution in a reasonable amount of time. According to [5], "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 sub problems. They use mixed integer programming at the loading part and heuristics at the scheduling part"

Before starting to IPPS problem it is better to see some surveys on this problem. [7 and 9] are literature survey examples on IPPS problem. If we list some works on IPPS, [1, 10 and 17] are some early examples on IPPS problem. Following works are more recent works on IPPS problem; [7, 9, 18 and 25] are the recent work examples on IPPS problem. Another popular research topic is SWDDA problem. Here scheduling is tried to be integrated with due date assignment. There are hundreds of works on SWDDA problem also. For a good review on SWDDA problem it is better to see [26]. If we disintegrate due date assignment from scheduling function, then we may assign poor due dates which are unnecessarily far due dates or unrealistically close due dates. On the other hand, if we perform scheduling independently we may schedule close dates later and schedule far due dates earlier and unnecessarily we may increase weighted earliness and tardiness costs. Conventionally tardiness is punished but according to JIT environment we should penalize both earliness and tardiness costs. Since nobody desires far due dates and far due dates cause loss of customer good will, price reduction, loss of firm's good reputation and worse customer loss. That is why at this research we penalized all weighted earliness, tardiness and due date related costs. At the literature due dates are given without considering importance of the customers, but in this research, we assigned due dates according to the weights of the jobs. Important jobs are assigned closer due dates, and this provided substantial improvement at the overall penalty function. If we look at literature for SWDDA problems, we can see SMSWDDA (Single machine scheduling with due date assignment) and MMSWDDA (multiple machine scheduling with due date assignment) problems. At the former case we have single machines and multiple jobs to be scheduled with due date assignment. At the latter case we have multiple machines and multiple jobs to be scheduled and due dates are to be assigned. At this research we have m machines and n jobs to be scheduled and due dates are to be assigned. Unlike many works in literature we assign separate due dates for each job. So, our problem is job shop scheduling with separate due date assignment for each job integrated with process plan selection. Here we assign earlier due dates to more important customers.

For SMSWDDA problem it is better to see [2, 27 and 38].

For MMSWDDA problem we can give following works as examples; [39 and 43].

Numerous works are on common due date assignment. For example, if we give due date for the jobs to be assembled we assign common due date. But at this research we assign unique due dates for each of the customer.

More recent works on SWDDA problem can be listed as follows; [38, 44 and 57].

4. DEFINITION OF THE PROBLEM

We studied a new problem where there are only a few works are done. Traditionally three manufacturing functions, process planning, scheduling and due date assignment are performed independently. Although recently there are hundreds of works are done on IPPS and SWDDA problems, there are few examples on IPPSDDA problem. We tried to integrate process plan selection with WATC weighted dispatching and WPPW weighted due date determination. At the second function we used mainly wo rules which are WATC and SIRO (Service in random order) rules. At the first rule we scheduled jobs according to a powerful dispatching rule and at the second rule we scheduled according to SIRO rule to see a poor scheduling results and compare with a better result. At the third rule we used mainly two due date determination rules where a strong rule WPPW is used to find better due dates and a poor RDM (Random) rule to see when due dates are determined randomly. We studied three shop floors for IPPSDDA problem. Characteristics of small, medium and large shop floors are represented at Table I. If we explain small shop floor as an example; There are 50 jobs, 20 machines, each job has 5 alternative routes and each route has 10 different operations. Operation times assume integer values practically in between 1 and 30 according to a normal distribution given at Table 1.

Table 1. Shop floors

	Small Shop Floor	Medium Shop Floor	Large Shop Floor
# of machines	20	30	40
# of Jobs	50	100	200
# of Routes	5	5	3
Processing Times	[(12+z*6)]	[(12+z*6)]	[(12+z*6)]
# of op. per job	10	10	10

At the beginning we tested unintegrated version for hybrid search and for ordinary solution. After that we integrated process plan selection with WATC scheduling, but due dates are randomly determined. Here we tested ordinary solution and hybrid search. Later we integrated WPPW due date determination with process planning but this time jobs are dispatched by using SIRO rule. Here again hybrid search and ordinary solution is observed. At the end we tested full integration where process planning, WATC dispatching and WPPW due date assignment are integrated. Here we observed hybrid search, random search and ordinary solutions. Totally we observed and compared nine different combinations explained at section V. As a solution technique we applied random search, hybrid search and ordinary solutions which are explained at the next section. We assumed one shift per one working day which makes 480 minutes per day. As a punishment function we panelized weighted earliness, tardiness and due date related costs. To minimize weighted cost terms, we used weighted due date assignment and gave closer dates for more important jobs and we applied weighted dispatching and we scheduled important customers first. Each cost terms are given below where PD(j) is the penalty of due-date for job j, PE(j) is the penalty of earliness for job j, PT(j) is the penalty of tardiness for job j, Penalty for a job is Penalty(j) and Total penalty for all jobs are as follows;

$$P.D = weight\ (j)*8*(Due\text{-}date/480) \quad (1)$$

$$P.E = weight\ (j)*\ (5+ 4*(E/480)) \quad (2)$$

$$P.T = weight\ (j)*(10 + 12*(T/480)) \quad (3)$$

$$Penalty(j)= P.D(j) + P.E\ (j)+ P.T(j) \quad (4)$$

$$Total\ Penalty = \sum_j P_j \quad (5)$$

5. SOLUTION METHODS

We used three methods to produce solutions for the different level of integrations. Two search methods are compared with each other and with ordinary solutions to prove benefits of searching and superiority of hybrid search over random search. Since only scheduling problem is NP-Hard problem and IPPSDDA problem is much harder problem we applied hybrid and random searches as metaheuristics in solution.

5.1. Ordinary Solution

Three populations are used in hybrid search. Initial iterations are random iterations and later we apply genetic iterations. At genetic iterations we need main population, crossover population and mutation population. At crossover we produce four pairs of chromosomes from four pairs of chromosomes chosen from previous step main population. At mutation we select five chromosomes from previous step main population and we produce new five chromosomes applying mutation operator to selected chromosomes. After that we select best 10 chromosomes from 23 chromosomes for the new main population. By doing this we complete one step of genetic iterations. At random iterations we randomly produce crossover and mutation population. At the beginning we produce three populations randomly and we select best ten chromosomes of these randomly produced three populations to build up starting main population. Starting main population is used as ordinary solutions and no iterations applied yet. Ordinary solutions are compared with hybrid and random searches to observe the contributions of the search methods over performance function.

5.2. Random Search

Another method we used is random search. Here we applied undirected search. To be fair with hybrid search we used same size of populations at genetic search and random search. We used a main population with size 10, a crossover population with size 8 and a mutation population with size 5. We applied 200, 100 and 50 random iterations for the three-shop floor respectively. At every iteration we produce brand new solutions randomly as big as crossover population and mutation population. Later out of old main population, new randomly produced crossover population and new randomly produced mutation population we produce new main population with size ten. These chromosomes are the best ten chromosomes out of 23 chromosomes. Required CPU times for random search and results of random search are listed at Table 2, 3, and 4 and summarized at Figure 2, 3, and 4 respectively.

5.3. Hybrid Search

We used hybrid search as the best candidate solution technique. Here we started with random search because at the beginning marginal benefit of random search is high and later we continued with genetic search because of the power of genetic search. At first, we determined genetic and random search ratio for every shop floor, and hybrid search parameters are given at Table 2. As it is mentioned, we have three populations, main, crossover and mutation populations. While applying random search we produce crossover population with 8 chromosomes randomly and we produce mutation population with size 5 randomly. Out of 23 chromosomes of previous main population and randomly produced crossover population and mutation population we select best ten chromosomes for the new main population and we complete one random iteration. After some predetermined number of random iterations, we switched to genetic iterations. At the genetic search part, we use four pair of chromosomes from the main population and apply crossover operator to these chromosomes to produce new four pair of offspring's. Again, we select five chromosomes from the main population from mutation and we produce new five offspring for mutation population. By using previous main population and genetically produced crossover population and mutation population we select best ten chromosomes for the new main population. Thus, we complete one genetic literation. Summarized results and required CPU times for hybrid search are given at the Table 2, 3 and 4 and illustrated at Figures 2, 3 and 4. We represented problem by using chromosomes have (n+2) genes. First two chromosomes represent due date assignment rule and dispatching rule. Remaining genes represent one selected route among alternatives for every job. Figure 1 represents a sample chromosome.

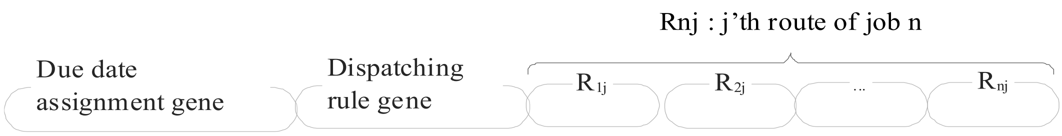

Figure 1. Sample chromosome

When we analyze the problem, we can see that first two gens have much more impact on performance measure compared to the remaining genes. For this reason, we selected these two genes for crossover and mutation with much more probability compared to the remaining genes. Dominant gene approach is useful where dominate genes exist. Mainly two types of due date assignment rules are used. For internal and weighted due date assignment we used WPPW rule and for external due date assignment we used RDM (Random) due date assignment rule. Write the different multipliers and constants first gene takes one of ten different values as in summarized at Table 2 and Appendix A.

Table 2. Due-date assignment rules

Method	Multiplier	Constant	Rule No
WPPW	k_x=1, 2, 3	q_x=q_1, q_2, q_3	1, 2, 3, 4, 5, 6, 7, 8, 9
RDM			10

We used mainly two scheduling rules where WATC is used as a powerful heuristic as weighted scheduling rule and SIRO is used instead of a poor dispatching rule for the comparison purpose. With the different multipliers second gene takes one of four different values.

Table 3. Dispatching rules

Method	Multiplier	Rule No
WATC	k_x=1, 2, 3	1, 2, 3
SIRO		4

6. COMBINATIONS COMPARED

According to different integration levels and used solution techniques, nine different combinations are compared. Four of the combinations use hybrid search, four of them is ordinary solution for different integration levels. Final one is the random search solution for the full integration level. If we explain combinations with hybrid search and random search, we can give following explanations below.

- **SIRO-RDM (Hybrid):** At this level of integration with hybrid search, we schedule jobs according to service in random order rule and assign due dates randomly. Thus, there is no integration of process plan selection, scheduling and due date assignment.
- **WATC-RDM (Hybrid):** Here we integrated WATC scheduling rule with process plan selection, but due dates are still determined randomly. Again, we used hybrid search as solution technique.
- **SIRO-WPPW (Hybrid):** This time we integrated WPPW weighted due date assignment rule with process planning but jobs are scheduled according to SIRO rule. Although this integration substantially improves the overall performance, SIRO rules strictly deteriorate the overall performance back.
- **WATC-WPPW (Hybrid):** This is the real goal of this study and here all three functions are integrated. Process planning is integrated with WATC weighted scheduling and WPPW weighted due date assignment and hybrid search is applied while solving the full integrated combination. This level of integration is found the best level of integration.
- **WATC-WPPW (Random):** Since this is the best level of integration we tested this combination with random search also. Results were promising but hybrid search is found better compared to random search. We compared nine different combinations above to observe how ordinary solutions are poor and searches are useful and how

hybrid search performs well compared to random search. Full integration with hybrid search found the best.

Table 4. Iteration parameters

Explanation	Small Shop Floor		Medium Shop Floor		Large Shop Floor
	Random Iter #	Genetic Iter #	Random Iter #	Genetic Iter #	Random Iter #
Random Search	200	-	100	-	50
Hybrid Search	50	150	25	75	15
CPU time Approx	157.8 secs		354.9 secs		551.4 secs

7. EXPERIMENTATION

We coded the program by using C++ programming language. Experiments are performed on a Laptop with 2 GHz processor, 8 GB Ram. Borland C++ 5.02 compiler is used while running the program. At the end required CPU times for each experiment are recoded and these CPU times are summarized at Table 4, 5 and 6 for each shop floor respectively. We represented problem by using a chromosome with (n+2) genes. Two genes represent due date assignment rule and dispatching rule respectively. Remaining genes represent selected routes of each job among alternatives. At the first gene mainly either WPPW weighted internal due date assignment rules or RDM external rule are used. At the second gene either WATC weighted scheduling rules or SIRO rule are used. We tested three shop floors, small, medium and large shop floors respectively. These shop floors are tested for nine different combinations according to integration levels and used solution techniques. Shop floor characteristics are summarized at table I at section III.

Initially we started with unintegrated combinations and we solved SIRO-RDM (Ordinary) and SIRO-RDM (Hybrid) combinations where jobs are scheduled according to SIRO rule and due dates are determined randomly and three functions are all unintegrated. Later we integrated weighted scheduling with process planning but due dates still assigned randomly. Here we tested WATC-RDM (Ordinary) and WATC-RDM (Hybrid) combinations and hybrid search is compared with ordinary solutions. After that we integrated WPPW weighted due date assignment with process plan selection, but jobs are scheduled in random order. This time we tested SIRO-WPPW (Ordinary) and SIRO-WPPW (Hybrid) combinations. Finally, we integrated all three functions and jobs are scheduled according to WATC rule and due dates are determined according to WPPW rule. Now we tested WATC-WPPW (Ordinary), WATC-WPPW (Hybrid) and WATC-WPPW (Random) combinations. When we compared nine different combinations we observed full integration with hybrid search as the best combination. Results are summarized at this section and interpreted at the conclusion section. First shop floor we tested was the smallest shop floor with 20 machines and 50 jobs. We have 5 alternative routes for each job. We applied 200 iterations at hybrid search and random search. For hybrid search, random search and genetic search ratios are summarized at Table 4. CPU times are given at Table 4. 200 iterations took approximately 100 to 250 seconds approximately. Results of small shop floor are summarized at Table 4 and Figure 2. From the results we can see that full integration with hybrid search gives the best results and ordinary solutions are the poorest.

Table 5. Comparison of nine types of solutions for small shop floor

	Best	Avg.	Worst	CPU Time
WATC-RDM-Ordinary	570.4	591.4	612.1	158.0
WATC-RDM-Genetic	464.7	474.7	478.9	139.0
WATC-RDM-Random	540.3	544.9	547.9	154.0
WATC-RDM-Hybrid	458.4	464.1	468.0	133.0
SIRO-WPPW-Ordinary	649.6	688.1	749.3	165.0
SIRO-WPPW-Genetic	527.9	531.2	534.4	161.0
SIRO-WPPW-Random	582.8	604.3	614.7	174.0
SIRO-WPPW-Hybrid	549.8	552.5	554.7	163.0
WATC-WPPW-Ordinary	475.0	530.5	591.3	170.0
WATC-WPPW-Genetic	385.6	386.8	387.6	160.0
WATC-WPPW-Random	397.9	404.6	407.9	160.0
WATC-WPPW-Hybrid	377.8	378.7	379.6	157.0

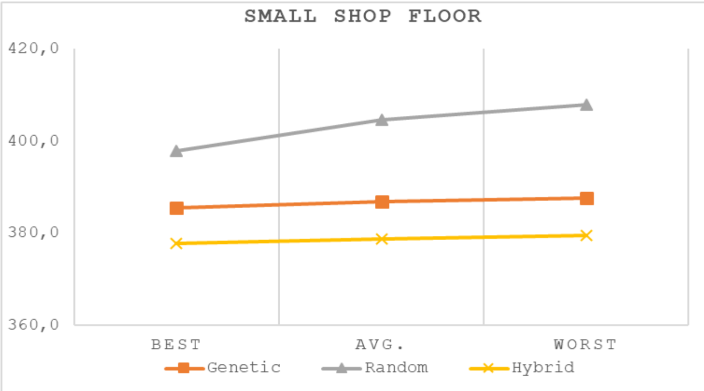

Figure 2. Small shop floor results

Second shop floor we tested was medium sized shop floor with 100 jobs and 30 machines. Here again every job has 5 alternative routes. Results of medium shop floor are summarized at Table 5 and figure 3. Here we applied 100 iterations at hybrid search and random search. 100 iterations took approximately in between 400 to 650 seconds. Full integration was found the best level of integration and hybrid search found the best technique to solve the problem.

Table 6. Comparison of nine types of solutions for medium shop floor

	Best	Avg.	Worst	CPU
WATC-RDM-Ordinary	1179.8	12387	1307.3	380.0
WATC-RDM-Genetic	1107.3	1111.8	1114.4	341.0
WATC-RDM-Random	1154.8	1174.6	1185.9	372.0
WATC-RDM-Hybrid	1072.9	1083.0	1086.9	134.4
SIRO-WPPW-Ordinary	1319.1	1368.5	1456.1	352.0
SIRO-WPPW-Genetic	1225.4	1233.5	1242.8	301.0
SIRO-WPPW-Random	1268.6	1283.5	1296.1	333.0
SIRO-WPPW-Hybrid	1229.0	1239.1	1244.6	296.0
WATC-WPPW-Ordinary	893.7	1032.3	1222.6	450.0
WATC-WPPW-Genetic	833.7	837.9	841.4	433.0
WATC-WPPW-Random	870.9	883.1	893.0	430.0
WATC-WPPW-Hybrid	844.4	846.9	848.2	436.0

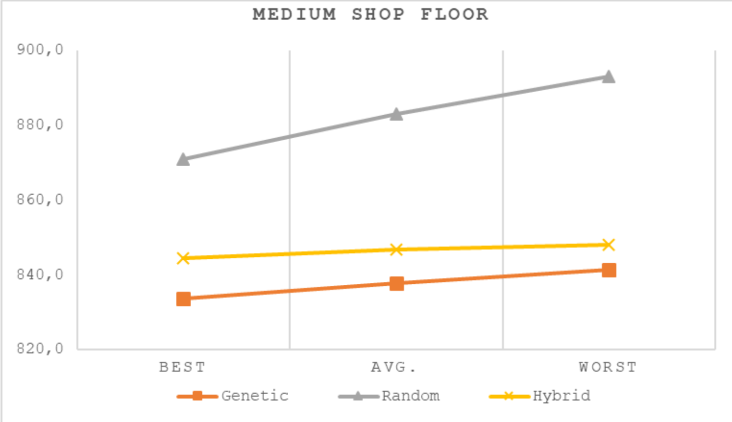

Figure 3. Medium shop floor results

Final shop floor is the biggest shop floor with 200 jobs and 40 machines. To save from computer memory usage and from CPU time we preferred 3 alternative routes for every job. CPU times were approximately in between 800 to 2600 seconds. Results of this shop floor are given at table VI and figure 4. From the results we can see hybrid search as the best solution technique and full integration level found the best integration level.

8. CONCLUSION

By this study we tried to observe improvements in overall performance measure by integrating process planning, weighted scheduling and weighted due date assignment. At this study we interered process plan selection with WATC weighted dispatching and WPPW weighted due date assignment. We started from the unintegrated combinations and step by step we integrated three functions to observe the improvement in overall performance measure as integration level increases. Although there are hundreds of works on IPPS and SWDDA problems, there are only a few works on IPPSDDA problem. At the works in literature due dates are determined endogenously and exogenously. While determining due dates, importance of customers was not considered. At this study we assigned relatively closer due dates for more important customers, thus we provided substantial improvements in performance measure. At this study we assigned due dates using WPPW weighted due date assignment rule. By giving closer dates for important customers we save substantially from weighted due date related costs. After assigning closer dates for important jobs we scheduled these jobs earlier by using WATC weighted scheduling rule. By scheduling important customers earlier, we save substantially from weighted tardiness. To maintain and increase improvements by weighted due date assignment we should apply weighted dispatching. According to the traditional approach tardiness is punished but JIT philosophy requires punishment of both earliness and tardiness. Since neither customer prefer far due dates, it was reasonable to penalize due date related costs. Far due dates mean price reduction, customer loss and loss of customer good will so it is better to assign reasonably closer due dates. In short, we panelized all weighted earliness, tardiness and due date related costs.

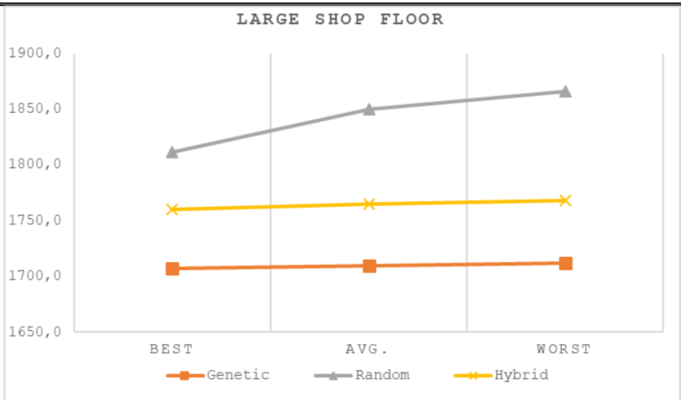

Figure 4. Large shop floor results

Table 7. Comparison of Nine Types of Solutions for Large Shop Floor

	Best	Avg.	Worst	CPU
WATC-RDM-Ordinary	2426.6	2543.9	2622.5	650.0
WATC-RDM-Genetic	2340.6	2343.3	2345.3	569.0
WATC-RDM-Random	2423.7	2439.1	2446.8	629.0
WATC-RDM-Hybrid	2319.1	2331.1	2337.2	252.8
SIRO-WPPW-Ordinary	2715.3	2848.8	3090.5	520.0
SIRO-WPPW-Genetic	2547.9	2565.8	2575.4	446.0
SIRO-WPPW-Random	2654.6	2675.8	2695.6	453.0
SIRO-WPPW-Hybrid	2514.4	2543.6	2555.6	444.0
WATC-WPPW-Ordinary	1924.8	2119.3	2493.9	690.0
WATC-WPPW-Genetic	1707.2	1710.0	1712.4	639.0
WATC-WPPW-Random	1811.8	1849.6	1865.9	661.6
WATC-WPPW-Hybrid	1759.9	1764.6	1768.0	663.0

We used hybrid search and random search as solution techniques. Since initial iterations are very important at random search and as iteration goes on marginal improvements get smaller, it is advisable to use random iterations at the beginning to scan the solution space better at the beginning. For example, if we pick a random number in between 0 and 1 expected value is 0.5 and marginal improvement is 0.5. Now if we pick tow random numbers than expected value of maximum of these two values is 0.75 so new marginal improvements is 0.25 so marginal improvement reduced sharply. Since genetic search is more powerful compared to random search it is better to use genetic search after initial iterations. So, we combined power of random and genetic searches and we used hybrid search as solution technique. At the beginning we tested totally unintegrated combinations where jobs are scheduled in random order and due dates are assigned randomly. So, we tested SIRO-RDM (Ordinary) and SIRO-RDM (Genetic) combinations and this level is found poor as expected. After that we integrated WATC weighted scheduling with process plan selection, but we determined due dates still randomly. Now we provided substantial improvements although due dates are still determined randomly. At this level we tested WATC-RDM(Ordinary) and WATC-RDM(Hybrid) combinations. Hybrid search is compared with ordinary solutions and hybrid search provided substantial improvements over performance measure. Later process plan selection is integrated with WPPW weighted due date determination rule but this time jobs are scheduled according to SIRO rule. Although by this integration substantial improvements are provided, SIRO rule strictly deteriorates the overall performance back. Here now we observed SIRO-WPPW(Ordinary) and SIRO-WPPW(Hybrid) combinations. Ordinary solutions are found very poor as expected. Finally, we integrated all three functions. Process planning, WATC weighted dispatching and WPPW weighted due date assignment are all integrated. Here we observed substantial improvements and reached best results especially full integration with hybrid search gave the best results. Ordinary solutions were still very poor and both search results provided substantial improvements and hybrid search outperformed random search. This time we tested WATC-WPPW (Ordinary), WATC-WPPW (Hybrid) and WATC-WPPW (Random) combinations. Even though conventionally process planning, scheduling and due date determination functions are handled independently, because of high interdependence of these functions force us to handle these functions concurrently. Since outputs of upstream functions become inputs to downstream function we should be careful with and integrate upstream functions with downstream functions. for instance, if we perform process planning independently than process planners may select continually same machines that they desired and may not select some preferred machines at all. This cause unbalanced machine loading, and some preferred machines become bottleneck and some undesired machines may be starving. Now if we perform scheduling and due date assignment separately we get poor results. If due dates are performed separately then we may assign unreasonably close due dates or unnecessarily far due dates. At the former case we may not keep our promises and we pay for high tardiness and loss of customer good will and we may reduce price or lost customer. At the second case nobody wants unnecessarily far due dates and we may have lost customer, we pay high for due date related costs and for high earliness costs. We may lose customer goodwill, or we may reduce price of the products. Now if scheduling is performed independently then we may schedule jobs with far due dates earlier and we pay unnecessarily for high earliness related costs or vice versa we pay for high tardiness costs. In short, we tried to select best route among alternatives that helps in overall performance and we assigned weighted due dates by using WPPW rule and more important customers get closer due dates that improves weighted performance measure substantially. At the same time, we schedule important customers have closer due dates earlier and this also helps in weighted overall performance. We used hybrid and random search techniques while solving the integrated problem. Full integration with hybrid search is found as the best combination. So, hybrid search outperformed random search and ordinary solutions were very poor compared to the search results.

APPENDIX A: DUE-DATE ASSIGNMENT RULES

- WPPW (Weighted Process Plus wait) Due=q_x*w1+w2*k_x*TPT (w1, w2 is determined according to weights) qx=q1, q2 or q3 q1=0.5*Pav, q2=Pav, q3=1.5*Pav, kx=1, 2, 3
- RDM (Random due assign.) Due=N~(3*P_{av},(P_{avg})^2)
- TPT=total processing time
- P_{avg}=mean processing time of all job waiting

APPENDIX B: DISPATCHING RULES

- WMS: Weighted Minimum Slack
- SIRO (Service in Random order): A job among waiting jobs is selected randomly to be processed.

NOTICE

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