Process Planning and Scheduling with WNOPPT Weighted Due-Date Assignment where Earliness, Tardiness and Due-Dates are Penalized

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Abstract

At literature there are numerous works on process planning and scheduling and works on scheduling with due date assignment. These three functions are not integrated much. Due dates are assigned without considering weights of the customer. In this study these three functions are integrated and due dates are given according to importance of the customers. Three shop floors are studied which are small, medium and large shop floor. Different level of integration of these three functions are tested and compared with each other and two search techniques used which are genetic search and random search and results are compared with ordinary solutions. As level of integration increased solutions became better and search techniques gave better result than ordinary solutions and genetic search seems better than random search.

Key words: Process Planning, Scheduling, Weighted Due-Date Assignment, Genetic Algorithm, Random Search

1. Introduction

Process planning, scheduling and due date assignment are three important manufacturing functions and treated separately. These three functions have effect on each other and it is better if they are treated simultaneously. At literature we can see numerous work on scheduling with due date assignment and works on integrated process planning and scheduling. But except the corresponding author of this study there are not many works on integrating these three functions. According to this research we tested different level of integration and we observed that higher integration level gives better results because of improved global performance.

Only scheduling sub problem belongs to NP Hard class problems and if we integrate process planning and due date assignment, problem becomes even more complex and belongs to NP hard problems. That’s why exact solutions are only possible for very small problems. As problems get bigger it becomes practically impossible to find exact solution of the problem. That’s why heuristic algorithms can and should be used to find a good solution of the problem in a reasonable amount of time. In this study according to different integration levels some ordinary solutions are compared with the solutions of genetic search and random search. Always search are found better than ordinary solutions and genetic search outperformed random search.

If we look at these there function consecutively; Process planning has been defined by Society of Manufacturing Engineers as the systematic determination of the methods by which a product is to

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be manufactured economically and competitively. Production scheduling is a resource allocator, which considers timing information while allocating resources to the tasks Zhang and Mallur [1]. "The scheduling problems involving due dates are of permanent interest. In a traditional production environment, a job is expected to be completed before its due date. In a just-in-time environment, a job is expected to be completed exactly at its due date" Gordon et al.[2].

Because of development in hardware, software and algorithms it becomes easier to perform some tasks and solve problems which could not be solved earlier. Recent developments in computer made it possible to prepare process plans. CAPP (Computer Aided Process Planning) is developed and it becomes easy to prepare process plans. Output of process planning is the input of scheduling so poor inputs cause many problem at shop floor. Process planners can select some desired machines repeatedly and may not select some undesired machines at all. This cause unbalanced machine loads and reduce shop floor utilization. In case of some undesired and unexpected occurrences such as machine break down, it is difficult to respond this situation, but if alternative process plans are prepared and if quality process plans are available then it becomes better and easier to schedule at shop floor level. In this case it becomes possible to react unexpected occurrences and to get balanced machine load and higher shop floor utilization.

Since every customer may not be as important as some other customers we had better schedule important customer first. In this study weighted and unweighted dispatching rules are used. Another very important application of this study is to assign close due dates for relatively more important customer and far due dates for less important customers. Weighted due date assignment is not treated at the literature much. Findings in this study suggest using weighted due dates assignment. We used WNOPPT (Weighted number of operation plus processing time) as due date assignment method. In this method due dates are assigned proportional to processing times plus a proportional amount of number of operations. Motivation in this study is to integrate three functions to improve global performance and use weighted scheduling to schedule important customer first and assign weighted due dates for important customers. Every aspects of this study contributed to overall performance.

As expected weighted tardiness is undesired but in JIT environment weighted earliness is also undesired. We also penalized weighted due dates and far due dates are penalized more. Far due dates may means customer ill will, customer loss and price reduction. So we should not give far due dates unnecessarily and also we should keep our promises. Sot it is very important to give close due dates for more important customer and keep our promises. According to performance measure it is better to give far due dates for less important customers and keep our promises. Jobs should be completed as near as given due dates.

2. Background and Literature Survey

As mentioned earlier there are numerous works on process planning and scheduling and on scheduling with due date assignment. Integration of these three functions is mentioned by Demir et al [3]. In this study integration of process planning and weighted scheduling with WNOPPT due-date assignment was studied. Weighted Earliness, Tardiness and due-dates are punished.

Weighted Earliness, Tardiness and due-dates are linearly punished with different proportion and proportional to time and importance of customer. In case of earliness and tardiness a fixed cost also added to the performance measure. Higher cost is given for tardiness compared to earliness.

If we look at works on IPPS (Integrated process planning and scheduling) we can see numerous works. If we list earlier works on IPPS, we can see following works. Khosnevis and Chen [4], Hutchinson et al [5], Chen and Khoshnevis [6], Zhang and Mallur [1], Brandimarte [7], Kim and Egbelu [8], Morad and Zalzala [9] worked in this area up to 2000.

If we look at more recent works, we can see following literature. Tan and Khoshnevis [10], Kim et al [11], Usher [12], Lim and Zhang [13], Tan and Khoshnevis [14], Kumar and Rajotia [15], Moon et al [16], Li et al [17], Leung et al [18], Phanden et al [19].

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, Demir et al [20].

Scheduling with due date assignment is also extensively studied topic. But scheduling with weighted due date assignment is not mentioned much. In this study close due dates are given important customer and these customers are scheduled first so we gained from weighted tardiness, due dates and earliness. Relatively far due dates are given for less important customers. A state of the art review on scheduling with due date assignment is given by Gordon et al [2]. Conventionally tardiness is penalized and length of due date and earliness are not penalized. Due dates are given independent from importance of customer. In this study weighted due date assignment with WNOPPT is integrated with process planning and weighted scheduling. Due dates can be determined internally or externally. If dates are determined externally out of our control we try to meet due dates but if we can determine due dates internally we look for best due dates which are the most profitable and dates with the least cost. According to modern approach earliness and due dates are also penalized as well.

If we look at the literature we can see SMSWDDA (Single machine scheduling with due date assignment) and MMSWDDA (multiple machine scheduling with due date assignment). Most of the works tries to find common due date for the jobs but this research finds different due dates for each customer.

At the literature there are not much work done on IPPSDDA (integrated process planning, scheduling and due date assignment). Demir and Taskin [21] studied IPPSDDA problem in a Ph.D. thesis. Later Demir et al [3] studied benefit of integrating these three functions. Benefits of integrating due date assignment with IPPS is studied by Ceven and Demir [22] in a Master of Science thesis.

As we mentioned earlier many works are on single machine scheduling with due date assignment. Following works are in this area: Panwalker [23], Gordon and Kubiak [24], Biskup and Jahnke [25], Cheng et al. [26], Ying [27], Nearchou [28], Xia et al [29], Gordon and Strusevich [30], and Li et al. [31].

There are examples on multiple machine scheduling with due date assignment problems. Adamapolous and Pappis [32], Cheng and Kovalyov [33], and Lauff and Werner [34] studied multiple machine problems.

In this research we have multiple customers and each will have their own due date according to importance of the customers and multiple machine job shop scheduling is integrated with due date assignment and process planning.

3. Problem Studied

With this research we studied IPPSDDA (Integrated Process Planning, scheduling and due date assignment). We have alternative process plans for each job. For small and medium sized shop floors we have five alternative routes for each job and for large shop floor in order to find solution in a reasonable amount of time we have three alternative routes. We integrated process planning with different dispatching rules and with WNOPPT weighted due date assignment rule. For the comparison purpose we also tested RDM (Random) due date assignment rule. WNOPPT assignment rule is used to represent endogenous due date assignment and RDM rule is used to represent exogenous due date assignment rule.

We have three shop floors as we mentioned earlier. First shop floor have 50 jobs and 20 machines and second shop floor has 100 jobs and 30 machines and third shop floor has 200 jobs and 40 machines. At small and medium shop floors jobs have 5 alternative routes and each route has 10 operations. For large shop floor we have 3 alternative routes and each route has 10 operations. In every case each operation has processing time according to the formula: Processing times = $\lfloor(12 + z * 6)\rfloor$ = nearest small integer practically in between 1 and 30. We produced processing times randomly and characteristics of each shop floor are given at Table 1.

Table 1. Shop Floors

Shop floor	Shop floor 1	Shop floor 2	Shop floor 3
# of machines	20	30	40
# of Jobs	50	100	200
# of Routes	5	5	3
Processing Times	$\lfloor(12 + z * 6)\rfloor$	$\lfloor(12 + z * 6)\rfloor$	$\lfloor(12 + z * 6)\rfloor$
# of op. per job	10	10	10

We penalized due dates, earliness and tardiness according to the formulas listed below. We assumed one shift per day and total 8*60 = 480 minutes per day.

All terms are punished linearly with different multipliers and constant in earliness and tardiness cases. Tardiness is punished more compared to earliness in terms of fixed and variable cost. All terms are multiplied with weight of customer to penalize more in case of important customer. Due dates are punished with proportional to the length of due date times 8 and weight of the customer. Earliness is punished with fixed cost 5 and 4 times earliness multiplied with the weight of the customer.

Tardiness is punished with fixed cost 10 and 12 times tardiness multiplied with the weight of the customer. Punishment functions for every jobs are given below where PD is penalty for due-date, PE is penalty for earliness and PT is penalty for tardiness;

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

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

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

4. Solution Techniques

We used two search techniques and ordinary solutions to compare. As directed search we used genetic algorithm and as undirected search we used random search. Each solutions are explained below:

Ordinary Solution: Here we used initial solutions for the comparison purpose. For genetic algorithm we defined three population. Main population, crossover population and mutation population. Initially randomly we produced three populations as big as main population, crossover population and mutation population. If we count best of these three populations as the initial starting main population and as the first iteration then we can say that ordinary solution is the result of first iteration. Since we just calculated best of initial three populations that's why it took negligible amount of time to find these results. Defined three populations are required in genetic search during the program run.

Random Search: This is undirected search and used for the comparison purpose. This search always gave better solutions than ordinary solutions. Marginal improvement in performance measure was found good at the very early iterations but sharply reduced as iteration goes on. Here we used three populations as we used in genetic search. We used same size of populations to be fair in comparison of random search, genetic search and ordinary solutions. At every iteration we produced brand new randomly produced populations as big as crossover population and mutation population and selected best of last step main population, newly produced crossover population and mutation population and resulting population is the next step main population.

Genetic Search: In this search we used similarly three populations at each iteration. Using the last main population with size ten, by applying crossover operator we produced 8 new solutions that constitutes crossover population and by applying mutation operator we produced 5 new solutions that make mutation population. For the next step main population we selected best 10 chromosomes out of 23 chromosomes of three populations.

We represented solutions as chromosomes which have (jobsize + 2) genes. First gene is used for due date assignment rules and second gene is used for dispatching rules. Remaining genes are used to represent each jobs route selected out of 5 or 3 depending on the size of shop floor. A sample chromosome is given at Figure 1.

DD	DR	R_{1j}	R_{2j}	.	.	.	R_{nj}

Where
DD: Due date assignment gene
DR: Dispatching rule gene
R_{ni} : i'th route of job n

Figure 1: Sample chromosome.

Due dates were assigned using mainly two different rules. First rule is weighted due date assignment rule WNOPPT and represents internal due date assignment and considers weights of each customer. Second rule is random RDM due date assignment rule that assign due dates randomly which represent external due date assignment. With the multipliers due date assignment gene takes one of 10 different values. These rules are explained below at Table 2 :

Table 2. Due-Date Assignment Rules

Method	Multiplier1	Multiplier2	Rule no
WNOPPT	k_x =1,2,3	k_y =1,2,3	1,2,3,4,5,6,7,8,9
RDM			10

Table 3. Dispatching Rules

Method	Multiplier	Rule no
WATC	k_x =1,2,3	1,2,3
ATC	k_x =1,2,3	4,5,6
WMS, MS		7,8
WSPT, SPT		9,10
WLPT,LPT		11,12
WSOT,SOT		13,14
WLOT,LOT		15,16
WEDD,EDD		17,18
WERD,ERD		19,20
SIRO		21

In order to dispatch nine different methods were used. Considering weights and different multipliers, the second gene took one of 21 different values. Dispatching rules are given and explained at Table 3 above.

5. Compared Solutions

SIRO-RDM(Ordinary): In this combination jobs are scheduled randomly and due dates are determined externally. This is the lowest level of integration. In this case three functions are unintegrated. We used here first iteration result as ordinary solutions.

SCH-RDM(Ordinary): Here we integrated scheduling with process plan selection but due dates are still randomly determined. We used ordinary solution in comparison with the search techniques.

SIRO-WNOPPT(Ordinary): With this combination we integrated due date assignment with process planning and as weighted due date assignment rule WNOPPT is used. We used initial results which represent ordinary solution.

SCH-WNOPPT(Ordinary): This is the highest level of integration. Here we integrated three functions. We selected process plans among the list and we dispatched jobs by using 21 dispatching rules and assigned due dates using WNOPPT. We used first step main population as ordinary solution.

SIRO-RDM(Genetic): At this lowest level of integration we applied genetic search as determined before. 200 iterations applied for first shop floor and 100 iterations for second shop floor and 50 iterations for the third shop floor.

SCH-RDM(Genetic): Here we integrated 21 dispatching rules with process plan selection and we applied genetic iterations as many as we mentioned above.

SIRO-WNOPPT(Genetic): In this level of integration we integrated weighted due date assignment with process plan selection and we applied certain number of genetic iterations.

SCH-WNOPPT(Genetic): This is the highest level of integration and genetic iteration are used.

SCH-WNOPPT (Random): As we mentioned above this is the highest level of integration and gives best results according to experiment results. That’s why we tested this combination with random search also.

We compared above nine solutions with each other to determine whether integration of scheduling with process planning or integration of process planning with weighted due date assignment or integrating all three functions are beneficial. We compared search techniques with ordinary solutions and we tested how directed search is well compared to undirected search. We presented result at experimentation part and made conclusion at the final part of the paper.

6. Experimentation

We coded problem using C++ which performs genetic or random iterations, assign due dates and schedule jobs according to given 21 dispatching rules. We run the program with a laptop with 2 GHz processor, 8 GB Ram and with windows 8.1 operating system and Borland C++ 5.02. CPU times are given at Table 4, 5 and 6.

We tested three shop floors for nine 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. Later we tested integration of weighted due date assignment with process planning and tested SIRO-WNOPPT (Genetic) and SIRO-WNOPPT (Ordinary). Finally we integrated process planning, scheduling and WNOPPT Due-date assignment and looked at solutions SCH-WNOPPT (Genetic), SCH-WNOPPT (Random), and SCH-WNOPPT (Ordinary). Explanations of these solutions are given at section 5.

We tested three shop floors for nine 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 according to formula$\lfloor(12 + z * 6)\rfloor$. We compared nine solutions and four of them are ordinary solutions for different level of integration. We used results of initial populations as the ordinary solutions. Four of the solutions are genetic search solutions and remaining solution is the random search solution. Since genetic search is superior compared to random search we tested random search with the best, fully integrated, combination.

For small shop floor we applied 200 iterations for random search and for genetic search. Times are given at Table 4 at the last column. It took approximately 100 to 250 seconds CPU time. Results of small shop floor are given at Table 4 and at Figure 2. According to results ordinary solutions are the poorest and integration found useful. As integration level increased solutions are found better. Genetic search found better than random search.

Table 4: Comparison of Nine Types of Solutions for Small Shop Floor

	Worst	Average	Best	Cpu time
SIRO-RDM(O)	464,82	447,55	432,15	
SCH-RDM(O)	451,96	407,88	363,21	
SIRO-WNOPPT(O)	522,14	487,18	428,01	
SCH-WNOPPT (O)	506,79	459,01	352,51	
SIRO-RDM(G)	397,38	395,98	393,46	117sec
SCH-RDM(G)	352,74	352,06	351,31	210sec
SIRO-WNOPPT(G)	388,36	385,89	379,92	243 sec
SCH-WNOPPT (G)	304,79	303,9	303,02	282 sec
SCH-WNOPPT (R)	315,56	312,23	302,1	256 sec

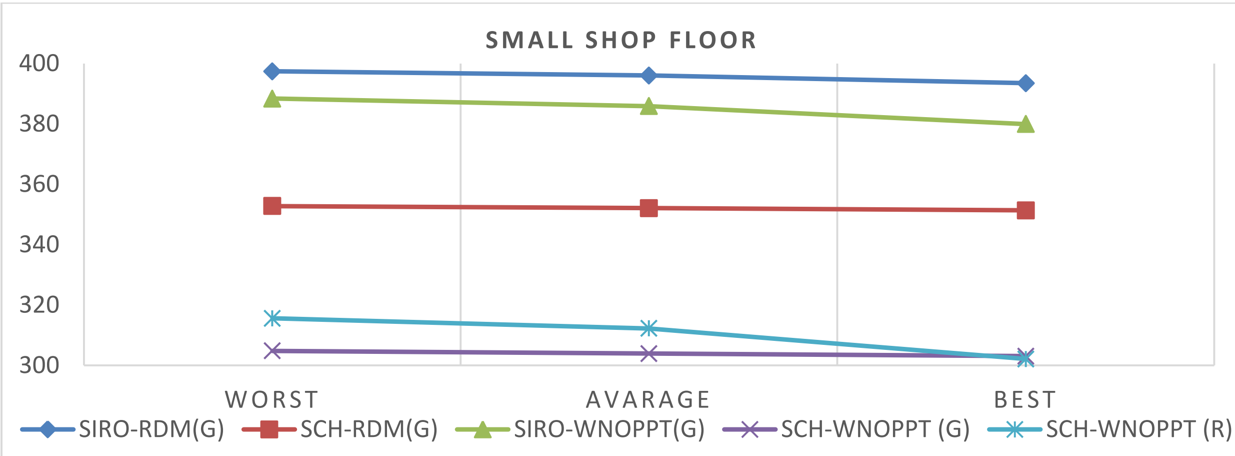

Figure 2: Small shop floor results

We found similar results for the medium shop floor. Results are given at Table 5 and Figure 3. It took approximately 400 to 800 seconds CPU time to complete 100 iterations. Integration found useful and highest level integration gave the best result and random search found better.

Table 5: Comparison of Nine Types of Solutions for Medium Shop Floor

	Worst	Average	Best	Cpu time
SIRO-RDM(O)	1124,6	1076,26	1038,92	
SCH-RDM(O)	1002,05	937,32	851,84	
SIRO-WNOPPT(O)	1253,41	1110,75	1051,15	
SCH-WNOPPT (O)	1082,29	900	777,48	
SIRO-RDM(G)	973,91	968,86	960,46	475 sec
SCH-RDM(G)	804,39	799,78	794,21	835 sec
SIRO-WNOPPT(G)	989,74	986,9	981,02	532 sec
SCH-WNOPPT (G)	759,38	758,97	758,55	777 sec
SCH-WNOPPT (R)	760,58	753,93	732,54	678 sec

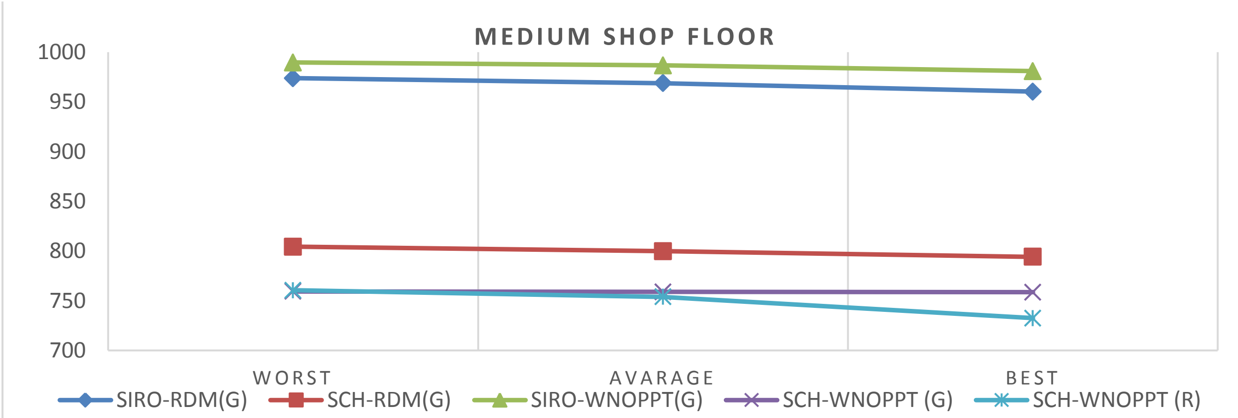

Figure 3: Medium shop floor results

Third shop floor is the biggest shop floor and similar results are found in this shop floor. It took approximately 1000 to 1600 seconds CPU time to complete 50 iterations. Results of third shop floor are summarized at the following Table 6 and Figure 4. According to results searches are found useful and genetic search found best. Integration found useful and highest integration with genetic search gave best result.

Table 6: Comparison of Nine Types of Solutions for Large Shop Floor

	Worst	Average	Best	Cpu time
SIRO-RDM(O)	2736,06	2698,08	2623,78	
SCH-RDM(O)	2543,38	2352,13	2190,29	
SIRO-WNOPPT(O)	2832,42	2613,24	2441,96	
SCH-WNOPPT (O)	2475,12	2141,46	1954,19	
SIRO-RDM(G)	2510,6	2505,37	2492,86	1084 sec
SCH-RDM(G)	2046,25	2045,02	2043,82	1065 sec
SIRO-WNOPPT(G)	2405,91	2397,53	2383,96	1604 sec
SCH-WNOPPT (G)	1737,25	1734,77	1729,67	1114 sec
SCH-WNOPPT (R)	1830,03	1810,09	1782,52	1350 sec

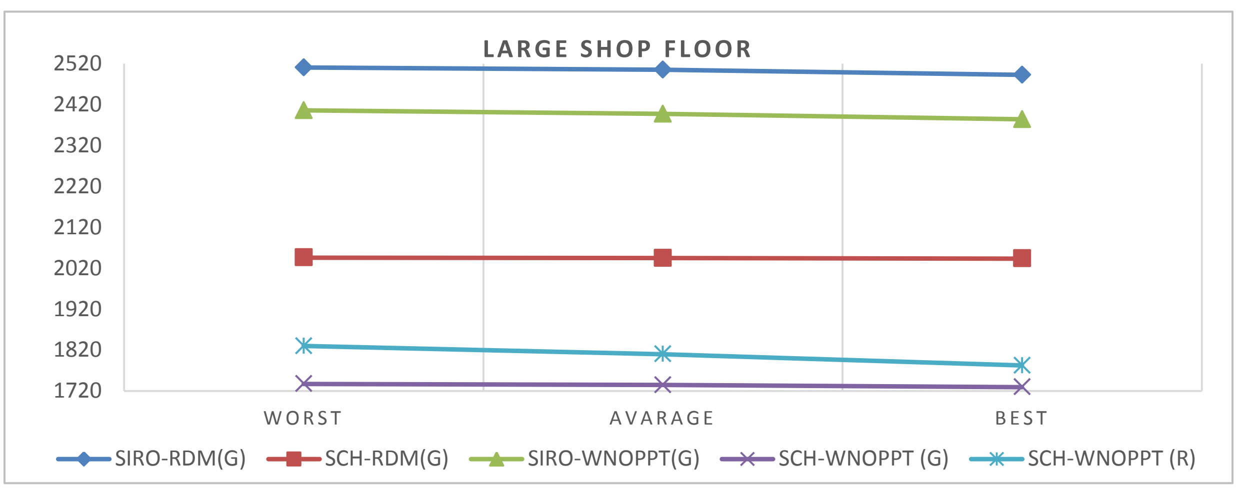

Figure 4: Large shop floor results

Conclusion

With this study we tried to integrate process planning, scheduling and WNOPPT weighted due-date assignment. We tested different level of integration and different search techniques.

At first we tested unintegrated combination. 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 exogenous, unintegrated due-date determination.

Later we integrated scheduling with process plan selection. At solution (chromosome), at dispatching rule gene we used with multipliers 21 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).

After that we integrated WNOPPT due date assignment with process plan selection. Scheduling is performed randomly and we used SIRO dispatching. We tested here SIRO-WNOPPT (Ordinary) and SIRO-WNOPPT (Genetic).

Finally we integrated three functions (process planning, scheduling and due-date assignment). At solution (chromosome), at scheduling gene we used 21 dispatching rules and at due-date assignment gene we used WNOPPT. Here we solved problem for *SCH-WNOPPT (Ordinary, SCH-WNOPPT (Random), SCH-WNOPPT (Genetic).* 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 nine types of solutions and their explanations are given at section 5.

We have shown that integration improves global performance and as integration level increases solutions become better. If we perform each functions sequentially and separately then they all try to get local optima and they don't care about the global optima. Output of process planning is an input to the scheduling. If process plans are made independently then process planner may select some machines repeatedly and some machines rarely. This may cause unbalanced machine load at shop floor and poor process plans may not be followed at the shop floor. If due dates are assigned independently from process plans and scheduling, then poor dates can be given that might give unnecessarily long due date, unnecessarily more earliness or we might be faced with unrealistically close due dates and unnecessarily high tardiness. If we give dates without being aware of importance of customers then sum of weighted due date, earliness and tardiness which is performance measure can be much higher than better results that we can find. So it is better to integrate all functions and while assigning due dates and scheduling we should take into account importance of customers.

In short integration level improves solution performance. So we should use highest integration level. Using weights while determining due dates and scheduling greatly effects weighted overall performance so we should take in to account importance of customers. Finally directed search outperforms undirected search and ordinary solutions are the poorest.

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